ARIZONA DEPARTMENT OF TRANSPORTATION

**REPORT NUMBER: FHWA-AZ99-455**

# DEVELOPMENT OF NEW PAVEMENT DESIGN EQUIVALENT SINGLE AXLE LOAD (ESAL)

**Final Report**

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206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

## Technical Report Documentation Page

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16. Abstract Establishing, maintaining, and enhancing the statewide network of roads are among the most important goals of any state highway agency. These require huge investments of both financial and human resources year in and year out. Accordingly, it makes good sense to apply sound engineering practices to ensure these resources are allocated wisely.

One of the fundamental and universally sought parameters that influence all new pavement and rehabilitation design decisions is *traffic*. For a given road segment, accurate estimates of current and projected traffic (in terms of Equivalent Single Axle Loads (ESALs)) can result in significant cost savings, either from the standpoint of initial construction cost or future maintenance and rehabilitation cost.

The primary objective of this project is to prepare a new ESAL design table for Arizona's highway network. This new table is based on analysis of current traffic data collection procedures, traffic forecasting methodology, and ESAL development procedures, including the assignment of traffic ESAL levels to the various highway segments. It is also based on new information such as provided by weigh-in-motion (WIM) systems. There are recommendations made for installing WIMs at a series of sites. System methodology for assessment of future needs for WIM and AVC installations is presented in this report focusing on technology installation, operation, and maintenance issues. The new ESAL table is provided to Arizona DOT in an electronic format on a CD ROM.

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

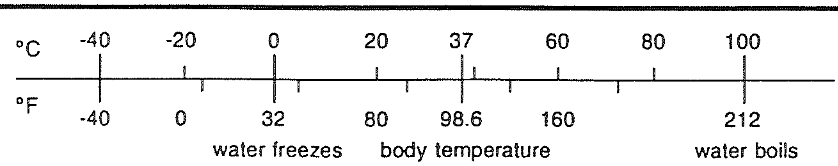
| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| ml | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | millimeters squared | $mm^2$ |
| $ft^2$ | square feet | 0.093 | meters squared | $m^2$ |
| $yd^2$ | square yards | 0.836 | meters squared | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | kilometers squared | $km^2$ |
| | | **VOLUME** | | |
| ft oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | meters cubed | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | meters cubed | $m^3$ |

NOTE: Volumes greater than 1000 L shall be shown in $m^3$.

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |

### TEMPERATURE (exact)

| Symbol | When You Know | Do The Following | To Find | Symbol |
|---|---|---|---|---|
| °F | Fahrenheit temperature | °F - 32 ÷ 1.8 | Celcius temperature | °C |




## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | millimeters squared | 0.0016 | square inches | $in^2$ |
| $m^2$ | meters squared | 10.764 | square feet | $ft^2$ |
| $m^2$ | meters squared | 1.19 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | kilometers squared | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | meters cubed | 35.315 | cubic feet | $ft^3$ |
| $m^3$ | meters cubed | 1.31 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams | 1.102 | short tons (2000 lb) | T |

### TEMPERATURE (exact)

| Symbol | When You Know | Do The Following | To Find | Symbol |
|---|---|---|---|---|
| °C | Celcius temperature | °C x 1.8 + 32 | Fahrenheit temperature | °F |

**METER:** a little longer than a yard (about 1.1 yards)
**LITER:** a little larger than a quart (about 1.06 quarts)
**GRAM:** a little more than the weight of a paper clip
**MILLIMETER:** diameter of a paper clip wire
**KILOMETER:** somewhat further than 1/2 mile (about 0.6 mile)

*SI is the symbol for the International System of Measurement

## ACKNOWLEGEMENTS

Nichols Consulting Engineers', Chtd. (NCE's) project team would like to thank all of those individuals whose contributions made the completion of this project possible. Dr. Estomih Kombe was an outstanding project manager, and the Technical Advisory Committee (TAC) consisting of Mr. Douglas Forstie, Mr. Larry Scofield, Mr. George Way, Mr. Kamel Alqalam, and Mr. Robert Pike (in addition to Dr. Kombe), provided valuable guidance and information. In addition, Mr. Mark Catchpole was an invaluable source of information regarding the Arizona Department of Transportation (ADOT) Traffic Planning Group's data collection and data processing methodologies.

The NCE project team was led by Dr. Sirous Alavi, the principal investigator. Mr. Kevin Senn was the project manager, and the project engineers were Mr. Weston Ott, Mr. Joseph Mactutis and Mr. Tony Lorenzi. The project team received valuable assistance from two consultants: Dr. Tom Papagiannakis of Washington State University and Mr. Earl Laird of TP&R. Last but not least, Mrs. Carol Chiappetta and Mrs. Barbara Milliken provided administrative support.

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AADT | Annual Average Daily Traffic |
| AAWDT | Annual Average Weekday Traffic |
| ADOT | Arizona Department of Transportation |
| ATR | Automated Traffic Recorder |
| AVC | Automatic Vehicle Classifier |
| CV | Coefficient of Variation |
| ESAL | Equivalent Single Axle Load |
| FHWA | Federal Highway Administration |
| GVW | Gross Vehicle Weight |
| KESAL | Thousand Equivalent Single Axle Loads |
| LDF | Lane Distribution Factor |
| LTPP | Long-Term Pavement Performance |
| NCE | Nichols Consulting Engineers |
| NRBA | No Recommendation by AASHTO |
| QC/QA | Quality Control/Quality Assurance |
| RV | Recreational Vehicle |
| SR | State Route |
| TPG | Traffic Planning Group |
| TWS | Truck Weight Study |
| TAC | Technical Advisory Committee |
| WIM | Weigh-in-motion |

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# CHAPTER 1: INTRODUCTION

## PROBLEM STATEMENT

Establishing, maintaining, and enhancing the statewide network of roads are among the most important goals of any State highway agency. These require huge investments of both financial and human resources year in and year out. Accordingly, it makes good sense to apply sound engineering practices to ensure these resources are allocated wisely.

For designing the new roadways (or rehabilitating existing ones), there are alternative methodologies available to engineers (including those used by ADOT) which call for a number of inputs that can significantly affect the design output. One of the fundamental and universally sought parameters that influences all new pavement and rehabilitation design decisions is *traffic*. For a given road segment, accurate estimates of current and projected traffic (in terms of Equivalent Single Axle Loads (ESALs)) can result in significant cost savings, either from the standpoint of initial construction cost or future maintenance and rehabilitation cost. In other words, accurate ESAL estimates help produce better pavement thickness designs and/or more realistic determinations of the performance lives of newly-constructed (or rehabilitated) pavements.

ADOT currently has an ESAL design table developed in the mid-80s that, for a given road segment, uses average ESAL vehicle factors, traffic volume, and vehicle classification data to generate base year, 10-year and 20-year estimates of accumulated ESALs. Since that time, significant progress has been made in the automated collection of vehicle weight and classification data. ADOT currently has 14 weigh-in-motion (WIM) sites and nine automatic vehicle classifier (AVC) sites maintained as a part of the Long-Term Pavement Performance (LTPP) Program. The Traffic Planning Group (TPG) maintains an additional six WIM sites and two AVC sites.

Thus, research was needed to evaluate and then enhance the existing ESAL design table incorporating the new monitoring data that is now available. It was also important to determine whether existing monitoring systems are collecting quality data, and whether the existing systems satisfactorily cover the key highway segments in Arizona.

## OBJECTIVE

The primary objective of the project was to prepare a new ESAL design table for Arizona's highway network. This new table is based on analysis of current traffic data collection procedures, traffic forecasting methodology, and ESAL development procedures including the assignment of traffic ESAL levels to the various highway segments. It is also based on new information such as those provided by WIM systems. Through the course of this project, a plan was developed and presented in this report for future review and update of the ESAL table on a routine (i.e., yearly) basis. There are recommendations made for installing 10 WIM sites. Also, a system methodology for assessment of future needs for WM and AVC sites is presented in this report focusing on technology, installation, operation, and maintenance issues.

## SCOPE

As stated in the Objective, the primary focus of this project was to develop a new ESAL table for future pavement designs. This table was developed using the best available data provided by ADOT. No data was collected by the project team.

## RESEARCH APPROACH (NEW ESAL TABLE)

There are three major types of data collected by ADOT, namely: vehicle counts, vehicle classification, and vehicle weights. The first two are collected either manually or automatically, while the latter is collected using WIM technology. The research team analyzed all types of available collected data and utilized the most representative data to produce the new ESAL table. The existing ESAL table consists of over 1,000 highway segments. These segments were not changed as a part of this study. Each segment has:

- An annual average daily traffic (AADT).
- The percent trucks based on the total traffic stream.
- The class breakdown of vehicle types based upon the Federal Highway's 13 class scheme.
- An annual growth factor and an ESAL value for both a flexible and a rigid pavement.

ADOT performs vehicle counts on all segments either annually (for high volume roads) or every 3 years (for all other roads). Classification data is collected either manually using 6-hour counts or automatically using 48-hour counts and also follows either an annual or a 3-year rotation. Given the costs of collecting classification data, a number of segments in the ESAL table are assigned to the most representative classification station. There are also a number of AVC/WIM systems that were installed primarily to support the LTPP program. The TPG does have four AVC/WIM sites that collect classification and weight data. The data from the WIM sites were utilized to determine the average ESAL factors for each Federal Highway Administration (FHWA) vehicle class 4-13. Final ESAL values were based upon the weighted average of the vehicles on each particular roadway segment. Sections that had a WIM representing its classification station used ESAL values based on measured data. Sections with no WIM systems representing their classification station used average ESAL factors based on a statewide average.

## OVERVIEW OF REPORT

Accomplishment of this project required the following tasks.

Task A. Review the scope of work and work plan at a kick-off meeting between the ADOT project Technical Advisory Committee (TAC) and key members of the investigating team.

Task B. Review the current traffic data collection, analysis and forecasting procedures used by ADOT. This included WIM and AVC information as well as other manual and automated collection techniques.

Task C. Review ADOT's procedures for developing its existing ESAL design table. The information gathered under Task B was used extensively in this task and a thorough review of the existing design tables (as provided by ADOT) was performed.

Task D. Recommend changes to the current procedures which can be incorporated into ADOT's practice. Formulate a plan for updating these in future years. The future data should be utilized to improve the existing traffic distribution, growth factor estimates, weight distribution algorithms, and ESAL calculations.

Task E. Prepare a new ESAL design table for the ADOT highway network based upon the new procedures and the best available traffic data.

Task F. Undertake an assessment of WIM and AVC data needs with due consideration as to cost, towards optimizing the contribution of continuous automated data sites in the development of ESAL table. Recommend 10-12 core sites along with another list of key sites, making an estimate of installed cost (where applicable), operation and maintenance costs in both equipment and staff.

This report contains a separate chapter for each task, as well as a final chapter containing the conclusions and recommendations of the research team.

# CHAPTER 2: KICK-OFF MEETING

Shortly after the awarding of the contract, a kick-off meeting was scheduled between the project team and the ADOT TAC. The purpose of this meeting was to discuss the key elements of the project, identifying the data sources that would be required and establishing key contact for providing the data.

## MEETING OVERVIEW

The kick-off meeting between ADOT project TAC and key members of the NCE team took place on December 2, 1998. NCE's principal investigator, project engineer, and technical advisor participated in a 1-day meeting with the TAC to review the scope of work and work plan in detail. A draft agenda for this meeting was prepared by NCE and was circulated among the project team (ADOT and NCE) for their review and comment in advance of the meeting date. A final meeting agenda based on input from the ADOT TAC and NCE project team was prepared and circulated just prior to the meeting date.

The meeting lasted over 3 hours, during which the NCE team was able to become familiar with the ADOT groups (and points of contact) involved the in traffic data collection and analysis. The project objectives were discussed and the work plan was thoroughly reviewed. The topics that received significant attention were the importance of getting as much information as possible regarding the existing ADOT ESAL tables and the traffic growth rates. It was decided that NCE would generate growth information based on the best available data and forecasting methods currently used by ADOT and other relevant agencies (i.e., the Maricopa Association of Governments in the Greater Phoenix Area). In the latter part of the meeting, NCE presented a wish list for data that needed to be evaluated in this project. Contact persons were identified for each data element. Table 2.1 summarizes all the materials provided to the NCE team.

Table 2.1. Data provided by ADOT.

| Data Type |
|---|
| Hardcopy and electronic version of existing ESAL table |
| ADT File from Traffic Planning Group--not known if it will be hardcopy or electronic |
| ADOT's adaptation of American Association of State Highway and Transportation Officials (AASHTO) ESAL Calculation (George Way and John Eisenberg) |
| "Interesting" trends in traffic data as identified by George Way (waywim.xls) |
| Data related to how growth factors are/were calculated |
| Data related to how growth factors are/were calculated |
| Vehicle volume and classification data |
| Transportation Planning Group WIM data--three WIM sites |
| Transportation Planning Group WIM data--fourth WIM site |
| List of weigh scales in Arizona |
| A1MRSNVJ.xls--Growth factors for key segments for 1997 |
| A2USSNVJ.xls--Seasonal distributions for key segments for 1997 |
| A3FTSNVJ.xls--Load factors by axle group for 1997 |

Table 2.1. Data provided by ADOT (continued).

| Data Type |
|---|
| Transportation Planning Group traffic count data |
| Transportation Planning Group classification data--138 sites with classification data for 1997 (vcls9704.xls); manual classification surveys from 1996, 1997 and 1998 |
| Relevant literature and reports from 1986 ESAL study |
| ADT Growth regression performed in 1990 (hardcopy) |
| Maricopa Association of Governments Conformity Analysis Appendices, Volume 2 |
| Pima Association of Governments Regional Transportation Improvement Program Tucson) |
| Information regarding base year for ESAL table |
| Input files for TRAFPROG or TRAF18K (as applicable) |
| Description of WIM systems for TPG WIM systems |
| Locations of classification sites |
| Definition of percent trucks in "Traffic on the Arizona State Highway System 1997" |
| Information regarding which fields in "Traffic on the Arizona State Highway System 1997" are measured and which are calculated |
| Description of how growth factors are determined in the Excel file containing regional growth factors |
| Documentation describing the Axle Factors by Axle Factor Group Excel spreadsheet--Chaparral may have, ADOT does not |
| Conversion from FHWA classification scheme to ADOT ESAL table classification scheme |
| Information on how much data the ADOT ATR sites collect |
| Information on regional groups 8 and 99 |
| 1996 classification data |

Following the meeting, NCE compiled the meeting notes and submitted a draft set to the project manager for review. Upon receiving feedback on those draft minutes, the official minutes were sent to all members of the TAC. The final minutes form this meeting are found in appendix A.

# CHAPTER 3: REVIEW PROCEDURES FOR TRAFFIC DATA COLLECTION, ANALYSIS, AND FORECASTING

The State of Arizona has a roadway network comprised of interstates, primary and secondary roads. The roadway network maintained by ADOT has been divided up into segments, which represent roadway sections with unique traffic and/or geometric constraints. The traffic data used in this study was collected almost entirely by ADOT. Understanding this data was of utmost importance before any meaningful progress could be made. This chapter reviews the traffic data collection, analysis, and forecasting methodologies currently used by ADOT.

## COLLECTED TRAFFIC DATA

The following is a brief description of each data type that is currently available for use in the new ESAL table. Each data group is important in either the determination of the number of vehicles passing a roadway segment or the type and weight of vehicles.

## AVERAGE ANNUAL DAILY TRAFFIC COUNTS

The vast majority (over 90 percent) of traffic volume counts performed by ADOT consist of either 24-hour or 48-hour counts using pneumatic road tubes or inductive loops. These counts are collected on a rotational basis, with some high volume areas being counted annually, but most areas being collected every 3 years. These counts are expanded into AADT values using a series of factors that will be described later in the ADOT data analysis section of this report.

## 6-HOUR MANUAL TRAFFIC COUNTS FOR VEHICLE CLASSIFICATION

This data is collected by ADOT on a 3-year rotational basis. The 6-hour manual classifications are not factored in any way and are used primarily to provide ADOT with two sources of information. The first piece of information is axle correction factors for pneumatic tube-based traffic counts and the second is the percentage of the AADT that is generated by commercial vehicles. The collection process of manual data is very labor intensive and costly. Only 30 percent of the approximately 140 classification stations use manual counts.

## 48-HOUR COUNTS FOR VEHICLE CLASSIFICATION

Like the 6-hour manual counts, the 48-hour counts are collected on a 3-year rotational basis. The data is collected with portable programmable classification equipment. As with the manual counts, axle correction factors and percentage of commercial vehicles is determined. However, unlike the 6-hour counts, the 48-hour counts are also used to determine AADT for the section of roadway in which they are collecting data. Seventy percent of the classification stations use these machine counts.

## AUTOMATED TRAFFIC RECORDER (ATR)

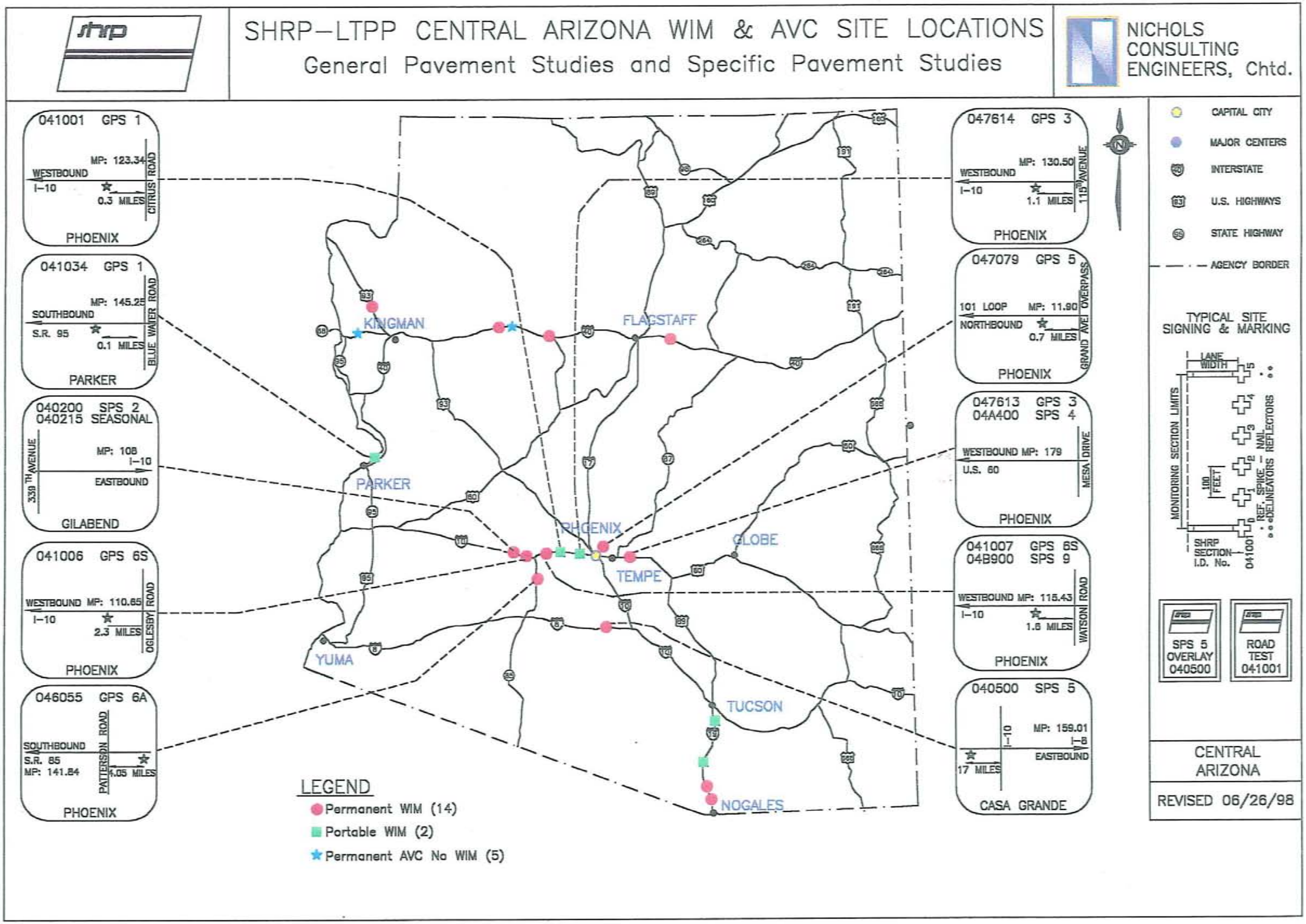
This data is collected by ADOT, and has passed all internal quality checks, for different time intervals throughout the year. This data was not supplied to NCE in raw form, but it is used by ADOT to develop growth, seasonal, and axle factors for AADT calculations. In discussions with ADOT, it was learned that there are approximately 80 ATR sites in Arizona that ideally would all be collecting data continuously. However, due to equipment maintenance requirements and manpower constraints, there are typically 50 ATR sites functioning at any one time.

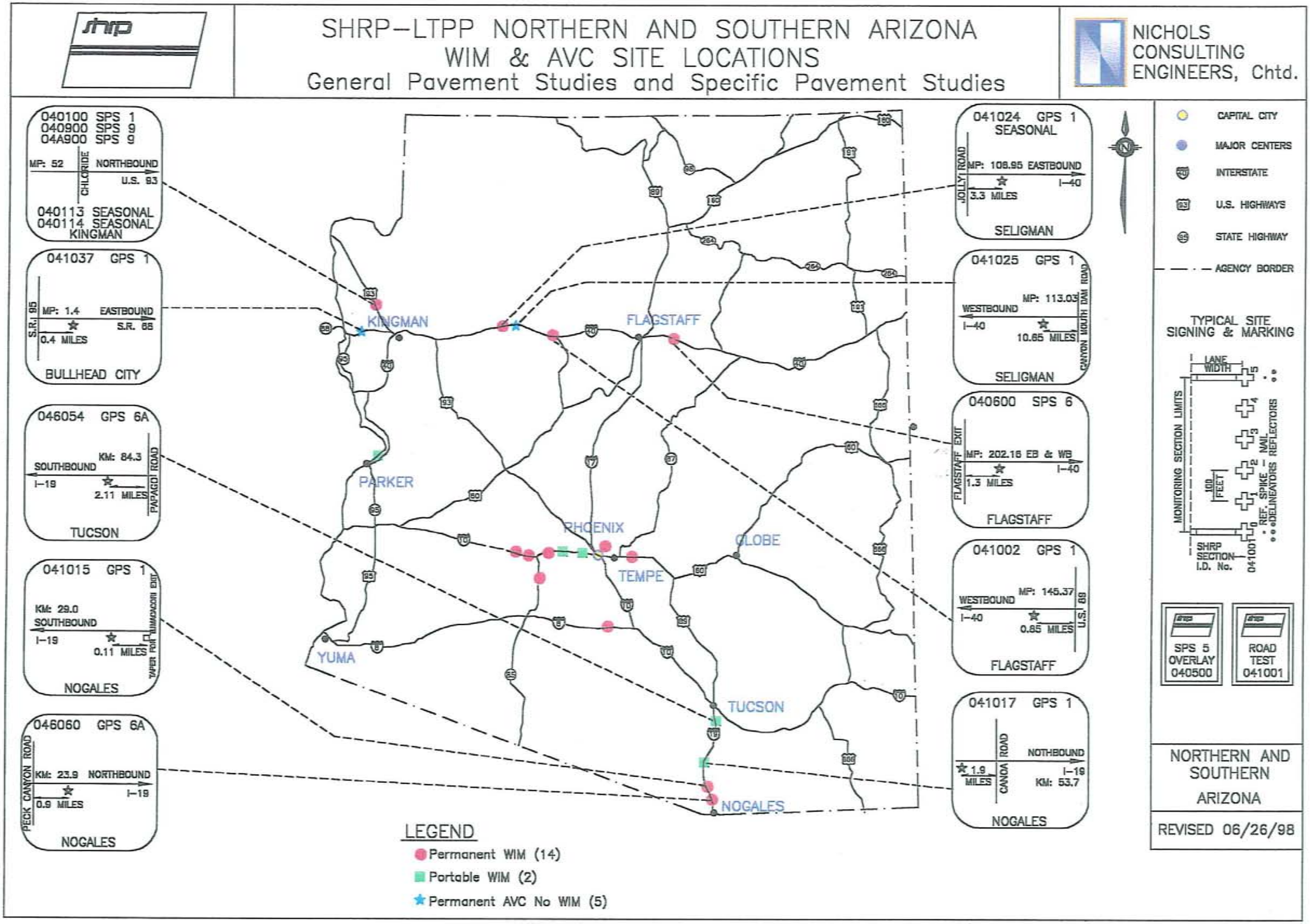
## LTPP AND ADOT TRAFFIC PLANNING GROUP (TPG) AVC/WIM COLLECTED DATA

As part of the LTPP program, there is a requirement to collect AVC and WIM data. ADOT currently has nine AVC sites and 16 WIM sites functioning as part of the LTPP program. Table 3.1 and figures 3.1 and 3.2 list these sites and show their locations. The TPG has four additional sites at which AVC/WIM data is collected. This data includes calculations of the yearly truck volumes by truck classification and trucks as a percent of total traffic.

Table 3-1. LTPP Arizona WIM/AVC sites.

| Arizona/ATRC Site # and Pavement Type | Site Location Route & MP (KIM) | SHRP ID | WIM/AVC | | |
|---|---|---|---|---|---|
| | | | Status | Make | Sensor |
| 025 RIGID | US-93 NB 052 | 0100 | PERM WIM | PAT | BENDING PLATE |
| 026 RIGID | I-10 EB 108 | 0200 | PERM WIM | IRD | BENDING PLATE |
| 009 FLEX | I-8 EB 159 | 0500 | PERM WIM | PAT | PIEZO |
| 202 RIGID | I-40 EB 202 | 0600 | PERM WIM | PAT | BENDING PLATE |
| 204 RIGID | I-40 WB 202 | 0600 | PERM WIM | PAT | BENDING PLATE |
| 020 FLEX | I-40 WB 145 | 1002 | PERM WIM | PAT | PIEZO |
| 012 FLEX | I-10 WB 110 | 1006 | PERM WIM | PAT | PIEZO |
| 011 FLEX | I-10 WB 115 | 1007 | PERM WIM | PAT | PIEZO |
| 005 FLEX | I-19 SB (029) | 1015 | PERM WIM | IRD | PIEZO |
| 018 FLEX | I-40 EB 106 | 1024 | PERM WIM | PAT | PIEZO |
| 010 FLEX | SR-85 SB 141 | 6055 | PERM WIM | PAT | PIEZO |
| 006 FLEX | I-19 NB (023) | 6060 | PERM WIM | PAT | PIEZO |
| 021 RIGID | SR-101 NB 011 | 7079 | PERM WIM | PAT | PIEZO |
| 024 RIGID | US-60 WB 179 | 7613 | PERM WIM | PAT | PIEZO |
| 019 FLEX | I-40 WB 113 | 1025 | PERM AVC PORT WIM | PAT | PIEZO |
| 015 FLEX | SR-68 EB 001 | 1037 | PERM AVC PORT WIM | PAT | PIEZO |
| 023 FLEX | I-10 WB 123 | 1001 | PERM AVC NO WIM | PAT | PIEZO |
| 007 FLEX | I-19 NB (054) | 1017 | PERM AVC NO WIM | PAT | PIEZO |
| 013 FLEX | R-95 SB 145 | 1034 | PERM AVC NO WIM | PAT | PIEZO |
| 008 FLEX | I-19 SB (084) | 6054 | PERM AVC NO WIM | PAT | PIEZO |
| 022 RIGID | I-10 WB 130 | 7614 | PERM AVC NO WIM | PAT | PIEZO |


SHRP-LTPP CENTRAL ARIZONA WIM & AVC SITE LOCATIONS
General Pavement Studies and Specific Pavement Studies
NICHOLS CONSULTING ENGINEERS, Chtd.
041001 GPS 1
WESTBOUND I-10 MP: 123.34 0.3 MILES CITRUS ROAD
PHOENIX
041034 GPS 1
SOUTHBOUND S.R. 95 MP: 145.25 0.1 MILES BLUE WATER ROAD
PARKER
040200 SPS 2
040215 SEASONAL
339 TH AVENUE MP: 108 I-10 EASTBOUND
GILABEND
041006 GPS 6S
WESTBOUND MP: 110.65 I-10 2.3 MILES OGLESBY ROAD
PHOENIX
046055 GPS 6A
SOUTHBOUND S.R. 85 MP: 141.84 PATTERSON ROAD 4.05 MILES
PHOENIX
047614 GPS 3
WESTBOUND I-10 MP: 130.50 1.1 MILES 115TH AVENUE
PHOENIX
047079 GPS 5
101 LOOP NORTHBOUND MP: 11.90 0.7 MILES GRAND AVE OVERPASS
PHOENIX
047613 GPS 3
04A400 SPS 4
WESTBOUND MP: 179 U.S. 60 MESA DRIVE
PHOENIX
041007 GPS 6S
04B900 SPS 9
WESTBOUND MP: 115.43 I-10 1.6 MILES WATSON ROAD
PHOENIX
040500 SPS 5
I-10 MP: 159.01 I-8 EASTBOUND 17 MILES
CASA GRANDE
KINGMAN
FLAGSTAFF
PARKER
PHOENIX
GLOBE
TEMPE
YUMA
TUCSON
NOGALES
LEGEND
Permanent WIM (14)
Portable WIM (2)
Permanent AVC No WIM (5)
CAPITAL CITY
MAJOR CENTERS
INTERSTATE
U.S. HIGHWAYS
STATE HIGHWAY
AGENCY BORDER
TYPICAL SITE SIGNING & MARKING
LANE WIDTH
MONITORING SECTION LIMITS
100 FEET
SHRP SECTION I.D. No.
041001
REF. SPIKE - NAIL
DELINEATORS REFLECTORS
SPS 5 OVERLAY 040500
ROAD TEST 041001
CENTRAL ARIZONA
REVISED 06/26/98



SHRP–LTPP NORTHERN AND SOUTHERN ARIZONA
WIM & AVC SITE LOCATIONS
General Pavement Studies and Specific Pavement Studies
NICHOLS CONSULTING ENGINEERS, Chtd.
040100 SPS 1
040900 SPS 9
04A900 SPS 9
MP: 52
CHLORIDE
NORTHBOUND
U.S. 93
040113 SEASONAL
040114 SEASONAL
KINGMAN
041037 GPS 1
S.R. 95
MP: 1.4
EASTBOUND
S.R. 68
0.4 MILES
BULLHEAD CITY
046054 GPS 6A
SOUTHBOUND
KM: 84.3
I–19
2.11 MILES
PAPAGO ROAD
TUCSON
041015 GPS 1
KM: 29.0
SOUTHBOUND
I–19
0.11 MILES
NOGALES
046060 GPS 6A
PECK CANYON ROAD
KM: 23.9
NORTHBOUND
I–19
0.9 MILES
NOGALES
041024 GPS 1
SEASONAL
JOLLY ROAD
MP: 108.95 EASTBOUND
I–40
3.3 MILES
SELIGMAN
041025 GPS 1
MP: 113.03
WESTBOUND
I–40
10.65 MILES
CANYON MOUTH DAM ROAD
SELIGMAN
040600 SPS 6
FLAGSTAFF EXIT
MP: 202.16 EB & WB
I–40
1.3 MILES
FLAGSTAFF
041002 GPS 1
MP: 145.37
WESTBOUND
I–40
0.65 MILES
U.S. 89
FLAGSTAFF
041017 GPS 1
CANOA ROAD
NOTHBOUND
1.9 MILES
I–19
KM: 53.7
NOGALES
KINGMAN
FLAGSTAFF
PARKER
PHOENIX
TEMPE
GLOBE
YUMA
TUCSON
NOGALES
CAPITAL CITY
MAJOR CENTERS
INTERSTATE
U.S. HIGHWAYS
STATE HIGHWAY
AGENCY BORDER
TYPICAL SITE SIGNING & MARKING
LANE WIDTH
MONITORING SECTION LIMITS
100 FEET
SHRP SECTION I.D. No.
REF. SPIKE ! NAIL
DELINEATORS REFLECTORS
SPS 5 OVERLAY 040500
ROAD TEST 041001
NORTHERN AND SOUTHERN ARIZONA
REVISED 06/26/98
LEGEND
Permanent WIM (14)
Portable WIM (2)
Permanent AVC No WIM (5)

For the LTPP data, quality checks of the collected AVC/WIM data were performed following the LTPP traffic Quality Control/Quality Assurance (QC/QA) procedure. Once the data is processed using the LTPP traffic software, a LTPP regional traffic engineer reviews the data, and a summary of questionable data is flagged. The flagged data is then compiled for review by a senior traffic engineer familiar with AVC/WIM data.

After the data review by the LTPP regional contractor is complete, the flagged QC/QA packets are sent to the State DOT that collected the raw data. A State traffic engineer reviews the flag list and decides if the DOT agrees with the findings. Once the edited flag list is received from the DOT by the LTPP regional contractor, the data is edited and summarized for use in the LTPP project. The edited LTPP AVC/WIM data is then summarized for used by pavement researchers and designers. For the ADOT TPG WIM data, the flag list process was done internally at NCE.

### Maricopa County Traffic Data

An investigation was conducted for incorporating the traffic information from Maricopa County into the ESAL tables. The information provided by Maricopa County consisted of a report entitled *Conformity Analysis for the Fiscal Year 1999-2003 MAG Transportation Improvement Program and the MAG Long Range Transportation Plan Summary and 1997 Update with 1998 Addendum*. The report provides more of a network summary of traffic information and is therefore not directly applicable to the segment specific ESAL table. It is important to mention, however, that the report states that "MAG (Maricopa Association of Governments) model estimates of 1997 VMT (vehicle miles of travel) are within one percent of the 1997 HPMS (Highway Performance Monitoring System) VMT that the Arizona Department of Transportation reported to the FHWA on July 16, 1998."[(1)] Assuming the HPMS VMT is calculated from the same ADOT traffic counts that the ESAL table is based on, it can be concluded that the ADOT data being incorporated into the ESAL table is sufficiently close to MAG data. Therefore, no special measures for incorporating MAG data into the ESAL table were taken.

### Pima County Data

Traffic data provided by Pima County was evaluated for its applicability and possible incorporation into the ESAL tables. The information provided by Pima County consisted of a map entitled *Traffic Volumes in Metropolitan Tucson and Eastern Pima County 1997-1998*, and maps illustrating AADT estimates for the year 2020. The maps illustrate AADT values for various freeway and arterial segments within the City of Tucson and portions of Pima County. As a test, the 1997-1998 AADT values for all of the freeway segments illustrated on the map were compared with the AADT values provided by ADOT within its report *Traffic on the Arizona Highway System 1997*.[(2)] The AADT values matched exactly for all segments. As the map lists the Arizona Department of Transportation as a source of traffic count information, this is not surprising. As it was concluded that Pima County data was based upon ADOT traffic counts, no special measures for incorporating it into the ESAL table were taken. However, a comparison of the Pima County AADT estimates for 2020 with the new ESAL table forecasted AADT values is reported in chapter 5.

**ADOT Data Analysis**

As mentioned in the previous section, traffic volume counts are collected over a 24-hour or a 48-hour period. In order to convert these counts into annual values, it is necessary to apply a number of factors. The methodology followed in expanding the counts to AADT values is explained below.

*Factor Groups*

As explained by the TPG, Arizona is divided into sixteen factor groups, with one extra group for "weird sites." The groupings are based solely on geographical locations and do not account for the functional class of the road located within the group (i.e., interstate highway or state route), although there are factor groups named for I-8, I-10, I-15, I-17, I-19, and I-40. The "weird site" grouping contains very few sections and these are primarily segments that have relatively high percentages of recreational traffic where seasonal and daily variations are not observed. These factor groups contain at least two continuously operating automatic traffic recorders (ATRs) located within the group, except for group 6 (one ATR), group 8 (zero ATRs), group 16 (zero ATR) and group 99 Weird Sites (zero ATRs). Group 8 had an ATR that is currently out of service but there are plans to have it repaired.

There are three different factors applied to the factor groups, namely: growth, seasonal, and axle factors. For sections that have no data collected during the year for which the traffic tables are being completed, the previous year's data is adjusted based on the factor group factors. The factor groups were determined by the contractor that processes ADOT's traffic data, and this process has been approved by FHWA.

*Growth Factors*

This data was provided by the TPG and contains the growth factors by growth factor group for Arizona (table 3.2). The growth factors are calculated by comparing AADTs from 1996 to those from 1997 at the ATRs. The growth rates from multiple ATRs in a growth factor group are averaged to determine a single value for all sections within a growth factor group. As mentioned above, if a particular section has not had any measurements made in 1997, then the growth factor for the respective growth factor group will be applied to the 1996 AADT. This value is a moving average from year to year and therefore does not reflect any long-term trends. For growth factor groups that do not contain a functional ATR, a growth factor of one is assumed.

The factors listed in table 3.2 for determining average annual weekday traffic (AAWDT) and average annual weekend traffic (AAWET) values had no relevance to this study.

Table 3.2. Growth factors.

| Growth Factor Group | Incl'd Sites 96-97 | AADT Growth Factor | Incl'd Sites 1997 | AAWDT Conversion Factor | AAWET Conversion Factor |
|---|---|---|---|---|---|
| 0-Yuma Metro | 2 | 1.2 | 2 | 0.99 | 0.95 |
| 1-I-8 | 1 | 1.17 | 2 | 0.92 | 1.06 |
| 2-I-10 West of PHX | 1 | 1.17 | 2 | 0.95 | 1.03 |
| 3-Phoenix Metro | 3 | 1.01 | 4 | 1.1 | 0.72 |
| 4-I-10 PHX-TUC | 1 | 1.1 | 2 | 0.94 | 1.05 |
| 5-Tucson Metro | * | 1.06 | 2 | 1.03 | 0.91 |
| 6-I-10 East of TUC | * | 1 | 1 | 0.95 | 1.09 |
| 7-I-17 | 1 | 0.88 | 3 | 0.85 | 1.22 |
| 8-I-19 | * | 1 | * | 0.91 | 1.09 |
| 9-I-40 West of FLAG | 1 | 0.99 | 2 | 0.96 | 1.07 |
| 10-I-40 East of FLAG | 1 | 1.08 | 2 | 0.97 | 1.06 |
| 11-Southwest | 1 | 1.19 | 3 | 0.93 | 1.06 |
| 12-West Central | 4 | 1.04 | 9 | 0.96 | 1.01 |
| 13-East Central | 7 | 1 | 14 | 0.95 | 1.01 |
| 14-North of I-40 | 3 | 0.91 | 6 | 0.99 | 0.97 |
| 15-Extreme SE Corner | 4 | 1.03 | 5 | 0.99 | 0.99 |
| 16-I-15 | * | 1 | * | 1 | 1 |
| 99-Weird Sites | * | 1 | * | 1 | 1 |

Note 1: AAWDT conversion factor = AAWDT/AADT. AAWDT includes Monday - Thursday.
Note 2: AAWET conversion factor = AAWET/AADT. AAWET includes Saturday - Sunday.
Note 3: Included sites must have at least one month of data.
Each month must have at least one day(s) of data for each day of week.
Note 4: * - Factor value was supplied by system operator.
Note 5: + - Factor value was supplied by system operator and replaced a value calculated from data.

*Seasonal Factors*

This data was provided by the TPG and contains the daily and seasonal adjustment factors by seasonal factor group for Arizona. These values are determined by comparing the AADT values by day of the week and by month of the year at each ATR in each growth factor group. In seasonal factor groups that have multiple ATRs, the values from each ATR are averaged. Each factor group has its own seasonal factor. Table 3.3 shows seasonal factor group 0.

For days of the month and months of the year for which no ATR data is available, these factors are estimated by the system operator.

*Axle Factors*

This data was provided by the TPG and contains monthly axle factors by axle factor group (table 3.4). Although monthly factors are shown, there is no variation from month-to-month for an axle factor within a particular axle factor group. The reason for this is that each value is determined based upon the vehicle classification data, and the classification data is only collected for a maximum of 48 hours at a particular site. If continuous classification data were to be collected, then this table could show variation from month-to-month.

These factors are only applied to data that was collected by road tubes (as opposed to the ATRs or inductive loops). When applying the axle factor, the value from the table should be doubled and then factored out to be a 24-hour count (if it was collected as a 48-hour sample) to obtain the adjusted raw volume.

## FORECASTING

Very little information was provided discussing forecasting methodologies utilized by ADOT, and the information that was provided fits most appropriately in the next chapter, which discusses the existing ESAL table.

Table 3.3. Seasonal factors for seasonal factor group 0.

| Seasonal Factor Group: 0-Yuma Metro | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Factor | Jan | # | Feb | # | Mar | # | Apr | # | May | # | Jun | # | Jul | # | Aug | # | Sep | # | Oct | # | Nov | # | Dec | # |
| SAF | 0.816 | 1 | 0.831 | 1 | 0.778 | 2 | 1.050 | * | 1.202 | 2 | 1.228 | 2 | 1.169 | 2 | 1.163 | 2 | 1.177 | 2 | 1.046 | 1 | 0.940 | 1 | 0.820 | 1 |
| Sunday | 1.170 | 1 | 1.057 | 1 | 1.162 | 2 | 1.118 | * | 1.084 | 2 | 1.086 | 2 | 1.005 | 2 | 1.054 | 2 | 1.132 | 2 | 1.029 | 1 | 1.079 | 1 | 1.282 | 1 |
| Monday | 1.009 | 1 | 0.952 | 1 | 0.990 | 2 | 0.962 | * | 1.011 | 2 | 1.017 | 2 | 1.024 | 2 | 1.020 | 2 | 0.930 | 2 | 1.333 | 1 | 1.090 | 1 | 0.951 | 1 |
| Tuesday | 0.979 | 1 | 1.084 | 1 | 1.019 | 2 | 1.035 | * | 1.052 | 2 | 1.031 | 2 | 1.079 | 2 | 1.074 | 2 | 0.998 | 2 | 1.032 | 1 | 1.139 | 1 | 0.913 | 1 |
| Wednesday | 1.041 | 1 | 1.042 | 1 | 1.011 | 2 | 0.984 | * | 1.065 | 2 | 1.010 | 2 | 1.056 | 2 | 1.054 | 2 | 1.022 | 2 | 0.990 | 1 | 0.855 | 1 | 0.942 | 1 |
| Thursday | 1.018 | 1 | 1.071 | 1 | 0.998 | 2 | 1.012 | * | 1.003 | 2 | 0.978 | 2 | 0.952 | 2 | 1.013 | 2 | 1.067 | 2 | 0.982 | 1 | 1.054 | 1 | 1.121 | 1 |
| Friday | 0.891 | 1 | 0.942 | 1 | 0.877 | 2 | 0.928 | * | 0.839 | 2 | 0.896 | 2 | 0.908 | 2 | 0.841 | 2 | 0.875 | 2 | 0.854 | 1 | 0.850 | 1 | 0.880 | 1 |
| Saturday | 0.937 | 1 | 0.887 | 1 | 0.998 | 2 | 0.982 | * | 1.007 | 2 | 1.008 | 2 | 1.005 | 2 | 0.988 | 2 | 1.046 | 2 | 0.901 | 1 | 1.015 | 1 | 1.017 | 1 |

Table 3.4. Axle factors.

| Axle Factor Group | Jan | # | Feb | # | Mar | # | Apr | # | May | # | Jun | # | Jul | # | Aug | # | Sep | # | Oct | # | Nov | # | Dec | # |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-Yuma Metro | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * |
| 1-I-8 | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * |
| 2-I-10 West of PHX | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * |
| 3-Phoenix Metro | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * |
| 4-I-10 PHX-TUC | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * | 0.39 | * |
| 5-Tucson Metro | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * |
| 6-I-10 East of TUC | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * |
| 7-I-17 | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * | 0.41 | * |
| 8-I-19 | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * |
| 9-I-40 West of FLAG | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * | 0.34 | * |
| 10-I-40 East of FLAG | 0.38 | * | 0.38 | * | 0.38 | * | 0.38 | * | 0.38 | * | 0.38 | * | 0.38 | * | 0.38 | * | 0.38 | * | 0.38 | + | 0.38 | + | 0.38 | * |
| 11-Southwest | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * |
| 12-West Central | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * | 0.44 | * |
| 13-East Central | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | + | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * | 0.45 | * |
| 14-North of I-40 | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * | 0.46 | * |
| 15-Extreme SE Corner | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * | 0.47 | * |
| 16-I-15 | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * |
| 99-Weird Sites | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * | 0.5 | * |

Note 1: # - This column indicates number of vehicle classification count sites.

Note 2: * - Factor value was supplied by system operator.

Note 3: + - Factor value was supplied by system operator and replaced a value calculated from data.

# CHAPTER 4: REVIEW PROCEDURES FOR DEVELOPING ESAL DESIGN TABLES

The focus of this chapter is to review the current ADOT ESAL table. This table was originally developed in 1986 and was most recently updated in 1997.

## CURRENT ESAL TABLE

As referenced in table 2.1, the current ADOT ESAL table was received in electronic and hardcopy formats. This table has been examined to determine the number of highway segments and analysis methodologies included within the spreadsheet. The document explaining ADOT's current method for calculating ESALs has also been received and reviewed. Table 4.1 is a portion of the existing ESAL table.

There are 1,040 segments in the existing ESAL table. Each row in the table contains the same types of information. The first three columns, highway and milepost, give the location of the traffic section (column 4). The traffic section number is unique and is generally consecutive, although there are occasions when the traffic volume increases to the point where a section needs to be subdivided. In these instances, a new section number is introduced (such as section 1161 in between sections 6 and 7 in table 4.1).

In chapter 3, it was noted that there are approximately 140 classification stations located throughout Arizona. The traffic sections have classification data from the most representative station, as determined by ADOT, assigned to them (e.g., sections 1-5 use the classification data from station 42). Columns 10-16 contain the information collected at these classification stations. Column 10 is the percent of commercial traffic, which ranges from 20 percent to 69 percent with an average of 43 percent. Columns 11-15 are the percent of each truck classification within the percent commercial traffic identified in column 10. Table 4.2 shows the range and mean values for each classification. Column 16 contains information on bus traffic, which ranges from 0.1 percent to 1.6 percent with a mean of 0.4 percent.

Column 9 contains the 1997 percent annual growth factors. These factors have generally remained unchanged since 1991. Some factors were manually changed over time by experts from ADOT using their best judgement observing changing trends between 1991 and 1997. Column 6 contains the two way AADT as calculated in 1991 (this is a discrete value in the spreadsheet). Columns 7 and 8, however, contain equations that calculate the AADTs in 1997 and 2017, respectively. The basic equation is: 1991 AADT*(1+(Year X-1991)*(percent annual growth)), where Year X is 1997 or 2017.

Table 4.1. Sample from existing ESAL table.

LT = LIGHT TRUCK MT = MEDIUM TRUCK TS = TRACTOR & SEMI-TRAILOR
TT = TRUCK & TRAILOR TST = TRACTOR & SEMI-TRAILOR

| | | | | TWO - WAY | | | 1997 PERCENT | CLASSIFICATION PERCENTAGES | | | | | | | 100% OF THE ONE-WAY ACCUMMULATED 18 KIP ESAL (THOUSANDS) THROUGH THE YEARS: | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TRAF | CLASS | 1991 | 1997 | 2017 | ANNUAL | | | | | | | | 1997 | 2007 | 2017 | 1997 | 2007 | 2017 | 1997 | 2007 | 2017 | 1997 | 2007 | 2017 |
| HIGHWAY | MILEPOST | SEC | STA | ADT | ADT | ADT | GROWTH | COM | LT | MT | TS | TT | TST | BUS | FLEXIBLE | | | RIGID | | | FLEXIBLE | FLEXIBLE | FLEXIBLE | RIGID | RIGID | RIGID |
| I 8 | 0.0 - 0.57 | 1 | 42 | 10172 | 12857 | 24172 | 4.4 | 44.7 | 66.8 | 13.2 | 16.4 | 2.1 | 1.5 | 0.3 | 488 | 6094 | 15113 | 546 | 6825 | 16927 | 488 | 6094 | 15113 | 546 | 6825 | 16927 |
| I 8 | 0.57- 2.23 | 2 | 42 | 11915 | 14989 | 27880 | 4.3 | 44.7 | 66.8 | 13.2 | 16.4 | 2.1 | 1.5 | 0.3 | 568 | 7104 | 17619 | 637 | 7957 | 19733 | 568 | 7104 | 17619 | 637 | 7957 | 19733 |
| I 8 | 2.23- 3.98 | 3 | 42 | 14553 | 18919 | 37838 | 5.0 | 44.7 | 66.8 | 13.2 | 16.4 | 2.1 | 1.5 | 0.3 | 717 | 8967 | 22238 | 803 | 10043 | 24906 | 717 | 8967 | 22238 | 803 | 10043 | 24906 |
| I 8 | 3.98- 7.63 | 4 | 42 | 13083 | 17479 | 37055 | 5.6 | 44.7 | 66.8 | 13.2 | 16.4 | 2.1 | 1.5 | 0.3 | 663 | 8284 | 20545 | 742 | 9279 | 23011 | 663 | 8284 | 20545 | 742 | 9279 | 23011 |
| I 8 | 7.63- 9.40 | 5 | 42** | 13418 | 18248 | 40147 | 6.0 | 44.7 | 66.8 | 13.2 | 16.4 | 2.1 | 1.5 | 0.3 | 692 | 8649 | 21450 | 775 | 9687 | 24024 | 692 | 8649 | 21450 | 775 | 9687 | 24024 |
| I 8 | 9.40- 12.21 | 6 | 41** | 16589 | 21964 | 45685 | 5.4 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 727 | 9091 | 22546 | 815 | 10182 | 25251 | 727 | 9091 | 22546 | 815 | 10182 | 25251 |
| I 8 | 12.21-14.24 | 1161 | 41 | 18000 | 23400 | 46800 | 5.0 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 775 | 9685 | 24020 | 868 | 10848 | 26902 | 775 | 9685 | 24020 | 868 | 10848 | 26902 |
| I 8 | 12.21- 21.03 | 7 | 41 | 8821 | 9774 | 13292 | 1.8 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 324 | 4045 | 10033 | 362 | 4531 | 11237 | 324 | 4045 | 10033 | 362 | 4531 | 11237 |
| I 8 | 21.03- 30.80 | 8 | 41 | 8322 | 9770 | 15437 | 2.9 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 324 | 4044 | 10029 | 362 | 4529 | 11232 | 324 | 4044 | 10029 | 362 | 4529 | 11232 |
| I 8 | 30.80- 37.95 | 9 | 41 | 8789 | 10687 | 18382 | 3.6 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 354 | 4424 | 10971 | 396 | 4954 | 12287 | 354 | 4424 | 10971 | 396 | 4954 | 12287 |
| I 8 | 37.95- 42.06 | 10 | 41 | 8443 | 10216 | 17367 | 3.5 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 338 | 4229 | 10487 | 379 | 4736 | 11745 | 338 | 4229 | 10487 | 379 | 4736 | 11745 |
| I 8 | 42.06- 54.96 | 11 | 41 | 8277 | 10214 | 18181 | 3.9 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 338 | 4228 | 10484 | 379 | 4735 | 11743 | 338 | 4228 | 10484 | 379 | 4735 | 11743 |
| I 8 | 54.96- 67.41 | 12 | 41 | 7226 | 8223 | 12006 | 2.3 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 272 | 3404 | 8441 | 305 | 3812 | 9454 | 272 | 3404 | 8441 | 305 | 3812 | 9454 |
| I 8 | 67.41- 73.48 | 13 | 41 | 5655 | 5994 | 7193 | 1.0 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 198 | 2481 | 6153 | 222 | 2779 | 6892 | 198 | 2481 | 6153 | 222 | 2779 | 6892 |
| I 8 | 73.48- 78.46 | 14 | 41 | 5416 | 5741 | 6889 | 1.0 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 190 | 2376 | 5893 | 213 | 2661 | 6600 | 190 | 2376 | 5893 | 213 | 2661 | 6600 |
| I 8 | 78.46- 87.04 | 15 | 41 | 5838 | 6188 | 7426 | 1.0 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 205 | 2561 | 6352 | 230 | 2869 | 7115 | 205 | 2561 | 6352 | 230 | 2869 | 7115 |
| I 8 | 87.04-102.23 | 16 | 41 | 6365 | 6938 | 9019 | 1.5 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 230 | 2872 | 7122 | 257 | 3216 | 7976 | 230 | 2872 | 7122 | 257 | 3216 | 7976 |
| I 8 | 102.23-106.51 | 17 | 41 | 7520 | 9009 | 14955 | 3.3 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 298 | 3729 | 9248 | 334 | 4176 | 10357 | 298 | 3729 | 9248 | 334 | 4176 | 10357 |
| I 8 | 106.51-111.42 | 18 | 41 | 7620 | 9266 | 15937 | 3.6 | 45 | 71.2 | 12.5 | 13.2 | 1.7 | 1.4 | 0.2 | 307 | 3835 | 9511 | 344 | 4295 | 10653 | 307 | 3835 | 9511 | 344 | 4295 | 10653 |
| I 8 | 111.42-115.14 | 19 | 15 | 6696 | 7741 | 11766 | 2.6 | 45 | 36.2 | 18 | 39.1 | 3.2 | 3.5 | 0.3 | 568 | 7098 | 17602 | 636 | 7949 | 19714 | 568 | 7098 | 17602 | 636 | 7949 | 19714 |
| I 8 | 115.14-115.62 | 20 | 15** | 3844 | 4813 | 8855 | 4.2 | 45 | 36.2 | 18 | 39.1 | 3.2 | 3.5 | 0.3 | 353 | 4413 | 10944 | 395 | 4942 | 12257 | 353 | 4413 | 10944 | 395 | 4942 | 12257 |
| I 8 | 115.62-119.42 | 21 | 15 | 3517 | 4002 | 5843 | 2.3 | 45 | 36.2 | 18 | 39.1 | 3.2 | 3.5 | 0.3 | 294 | 3670 | 9101 | 329 | 4110 | 10193 | 294 | 3670 | 9101 | 329 | 4110 | 10193 |
| I 8 | 119.42-140.81 | 22 | 16** | 5718 | 6061 | 7273 | 1.0 | 45 | 28.1 | 14.1 | 51 | 3.6 | 3.2 | 0.3 | 501 | 6263 | 15533 | 561 | 7015 | 17397 | 501 | 6263 | 15533 | 561 | 7015 | 17397 |
| I 8 | 140.81-144.57 | 23 | 16 | 7941 | 9704 | 16885 | 3.7 | 45 | 28.1 | 14.1 | 51 | 3.6 | 3.2 | 0.3 | 802 | 10027 | 24868 | 898 | 11231 | 27852 | 802 | 10027 | 24868 | 898 | 11231 | 27852 |
| I 8 | 144.57-151.68 | 24 | 16 | 7854 | 9550 | 16427 | 3.6 | 45 | 28.1 | 14.1 | 51 | 3.6 | 3.2 | 0.3 | 790 | 9869 | 24475 | 884 | 11053 | 27412 | 790 | 9869 | 24475 | 884 | 11053 | 27412 |
| I 8 | 151.68-161.53 | 25 | 62 | 8310 | 9307 | 13030 | 2.0 | 45 | 31.2 | 11.3 | 50.8 | 3.9 | 2.8 | 0.2 | 736 | 9203 | 22823 | 825 | 10307 | 25562 | 736 | 9203 | 22823 | 825 | 10307 | 25562 |
| I 8 | 161.53-167.53 | 26 | 62 | 5336 | 5720 | 7093 | 1.2 | 45 | 31.2 | 11.3 | 50.8 | 3.9 | 2.8 | 0.2 | 452 | 5656 | 14027 | 507 | 6335 | 15710 | 452 | 5656 | 14027 | 507 | 6335 | 15710 |

The table also includes two identical sets of ESAL values for 1997, 2007 and 2017. The first set (columns 17-22) are calculated by multiplying the value in each corresponding column (23-28) by 1 (e.g., column 23 multiplied by 1 equals column 17). The key value in columns 17-28 is found in column 23. This is the 1997 flexible ESAL value. This cell contains an equation that is found by taking the 1997 ADT (two-way) divided by two multiplied by percent commercial vehicles divided by 100 multiplied by 100 minus light trucks multiplied by 100 multiplied by 1.4 (or 1.7) multiplied by 365 divided by 1000 (i.e., (((((1997 ADT/2)*((% Com/100)))*((100-% LT)/100))*1.4 (or 1.7)*365)/1000)). The flexible 2007 (column 24) value takes the flexible 1997 value and multiplies it by 12.5, while the flexible 2017 ESAL value (column 25) multiplies the flexible 1997 ESAL value by 31. The corresponding rigid ESAL values (columns 26-28) are determined by multiplying the flexible ESAL value by 1.12.

Table 4.2. Range and mean values for Arizona truck classifications.

| | Light Truck | Medium Truck | Tractor and Semi-Trailer | Truck and Trailer | Tractor and Semi-Trailer |
|---|---|---|---|---|---|
| Minimum (%) | 28.1 | 3 | 0.3 | 0 | 0 |
| Maximum (%) | 95.2 | 36.6 | 53.8 | 5.3 | 5.6 |
| Mean (%) | 73 | 12.1 | 12.5 | 1.4 | 1.1 |

Discussions with ADOT personnel revealed that there have been a number of simplifying assumptions made that may not have been documented, but of which the ADOT materials group are well aware. The primary assumptions are that for 1997, the commercial vehicles (excluding the light truck category) contribute a factor of 1.4 ESALs per vehicle (except for the Interstate 40 and U.S. 93 corridors for which the factor is 1.7 ESALs per vehicle), the 10-year ESAL multiplier is 12.5, and the 20-year ESAL multiplier is 31. These numbers were determined to be defendable by the materials group and account for such factors as expected increases in tire pressures and vehicle weights over time.

# CHAPTER 5: RECOMMEND CHANGES TO CURRENT PROCEDURES

There is significant overlap between items in chapter 5 and their subsequent application in chapter 6. This is due to the close tie between the NCE team's recommendations and their subsequent effect on the revised ESAL table. Ideally, every segment in Arizona would have its own continuous and calibrated AVC/WIM system. However, the cost of this instrumentation (not to mention the labor to maintain the systems and collect and process the data) is prohibitive. The recommendations in this chapter are believed to be implementable without significantly affecting the current expenditures for traffic data collection.

## FHWA VEHICLE CLASSIFICATION SYSTEM

Vehicles traveling in the United States come in many shapes and axle configurations. This creates difficulties for State DOT personnel in the classification of vehicle types on roadway networks. The FHWA has developed two methods of vehicle classification that have been used in the Truck Weight Study (TWS). The two methods developed are the 6-digit classification system and the 13-bin classification system. The 13-bin system is currently the most accepted system and is the current FHWA required classification system (figure 5.1).

Prior to the 13-bin FHWA system; the USDOT used what is referred to as the 6-digit system. This system is extremely flexible; however, it produces many different vehicle types (i.e., more than 13). ADOT is currently using the 13-bin FHWA vehicle classification system.

The 13-bin system allows a better understanding of the vehicle types on the ADOT road network, and reflects the state-of-the-practice for State DOTs in the United States. Additionally, the 13-bin system can be easily reduced into the more general vehicle class system that has been used in the past (i.e., the LT, MT, TS, TT, TST scheme in the existing ESAL table) if necessary. Both the TPG and the LTPP data is reported in the 13-bin classification system, so no work will be required on behalf of ADOT to implement this classification scheme into the new ESAL table.

## TRAFFIC FORECASTING METHODOLOGY

As mentioned in chapter 4, there is not currently a mechanism by which AADT forecasts are updated aside from manually updating growth factors. The existing growth factors were determined by applying a linear regression to AADT data that extended through 1991.

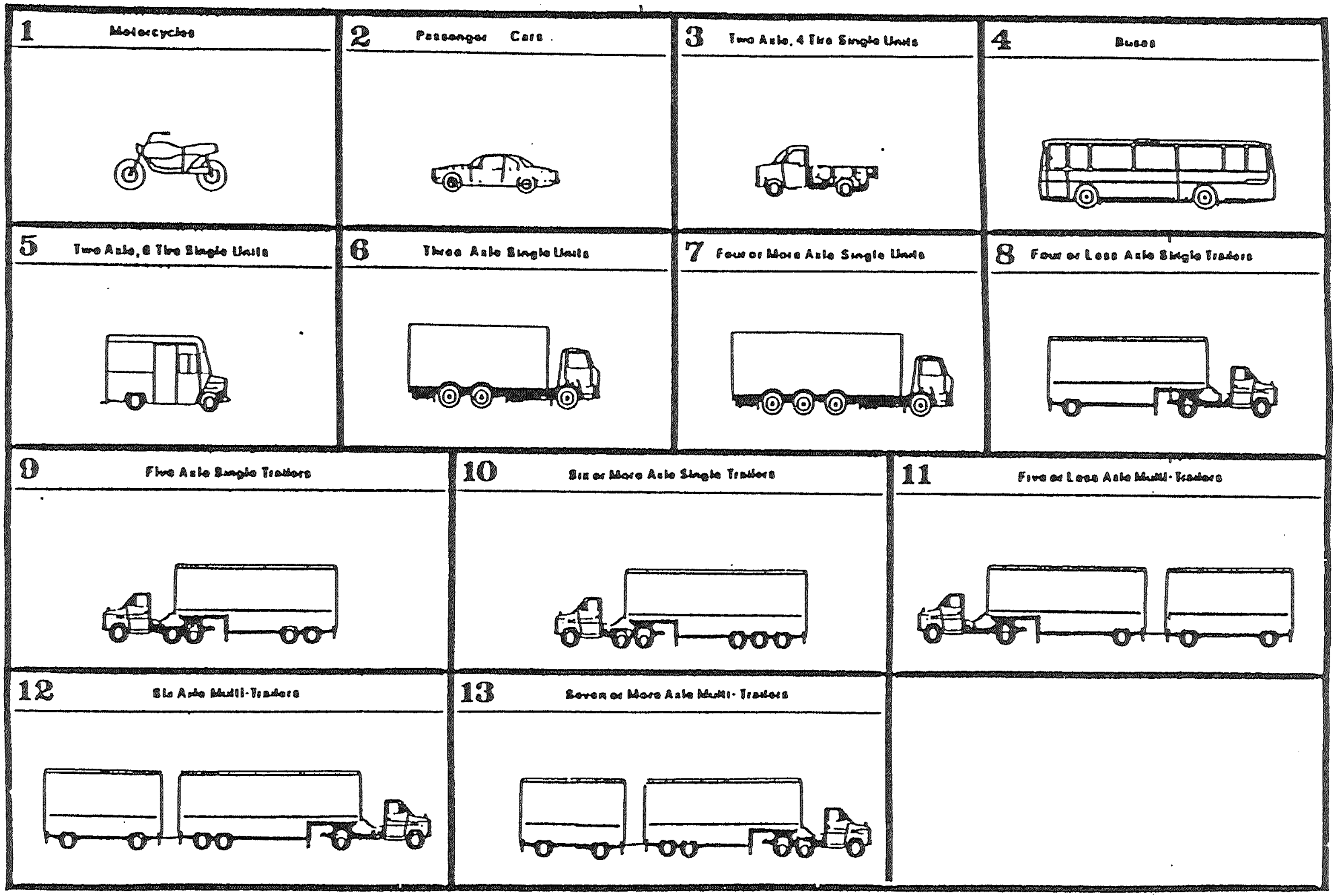



Figure 5.1. FHWA vehicle classification.

## NCE APPROACH TO AADT FORECASTING

The forecasting of AADT is important in the understanding of traffic movements and for the calculation of ESALs in the ADOT ESAL table. ADOT has been collecting AADT data for 1,040 traffic segment locations since 1974. This has been accomplished by manual surveys, automated counting equipment, and more recently by AVC and WIM systems. Upon the recommendation of the TAC, only the last 6 years of data was to be used in any forecasting models.

The forecasting of AADT for all segments is critical in the revisions to the ADOT ESAL table. The difficulty with forecasting traffic data is that not all traffic segments have the same pattern of traffic growth. Additionally, traffic growth is triggered by many factors that can not be foreseen or modeled. The NCE team decided to initiate the growth factor analysis with the assumption that a linear trend in growth exists for most traffic segments. However, given the relatively small data set (as sites where traffic volumes were collected every three years would only have two measured data points and four points calculated using growth factors), only about 40 percent of the data showed a strong linear correlation (i.e., $R^2 > 0.6$).

It was then determined by the project team that the most reasonable method to determine the AADT growth factors was to average the average annual growth factors for each year between 1992 and 1997. For sections with low AADTs, this resulted in some extremely large growth factors, and there was some discussion whether to limit the maximum annual growth, but it was decided that this would be outside the scope of the project (since more familiarity with each specific site was required) and should be decided by ADOT personnel. Sections with annual growth factors over 15 percent are identified in the new ESAL table. In future years, as AADT values are added, it is expected that fewer segments will need to be flagged as having questionable growth factors.

## NEGATIVE GROWTH

Another trend that was discovered in the AADT data during the analysis was that some sections exhibited negative growth trends. A negative trend in AADT will directly affect the trend in yearly and cumulative ESALs. After discussing this matter with the TAC, it was decided that the minimum growth factor for any section would be 2 percent, so sections with negative growth trends, or positive growth trends less than 2 percent, would be modified to have a growth factor of 2 percent.

## COMPARISON OF 2020 AADT ESTIMATES (PIMA COUNTY VS. NEW ESAL TABLE DATA)

As a quality assurance check, the 2020 AADT estimates from the maps provided by Pima County were compared with 2020 estimates of AADT from the new ADOT ESAL table. Table 5.1 contains a listing of the 2020 AADT values provided by Pima County, the 2020 AADT values computed by the new ESAL table, the percentage difference between the two, for 26 ADOT segments in Pima County and the *theoretical capacity* (this will be defined in chapter 6) of each segment. The majority of the 2020 AADT values have a percent difference of less than 40 percent. These numbers compare even better when they are constrained by the maximum theoretical capacity for each roadway segment. While there would still be segments that differ significantly (segment 533 is the prime example), other segments (e.g., 245 and 246) would match almost exactly. Considering the fact that 20-year traffic estimates are difficult to closely estimate, the NCE team feels that this comparison confirms the AADT forecasting methodology.

Table 5.1. Comparison of Pima County and ESAL table 2020 AADT values.

| ADOT Segment # | Pima County 2020 AADT | NEW ADOT 2020 AADT | % Diff. | Theoretical Capacity |
|---|---|---|---|---|
| **100** | 129,000 | 159,029 | -23.3 | 110,000 |
| **101** | 139,000 | 85,487 | 38.5 | 165,000 |
| **102** | 147,000 | 170,905 | -16.3 | 165,000 |
| **103** | 139,000 | 106,395 | 23.5 | 165,000 |
| **104** | 152,000 | 110,589 | 27.2 | 165,000 |
| **105** | 172,000 | 156,098 | 9.2 | 165,000 |
| **106** | 173,000 | 184,629 | -6.7 | 165,000 |
| **107** | 175,000 | 172,756 | 1.3 | 165,000 |
| **108** | 170,000 | 246,769 | -45.2 | 165,000 |
| **110** | 176,000 | 235,846 | -34.0 | 165,000 |
| **111** | 184,000 | 206,412 | -12.2 | 165,000 |
| **115** | 82,000 | 93,363 | -13.9 | 110,000 |
| **116** | 76,000 | 152,664 | -100.9 | 110,000 |
| **117A** | 66,000 | 160,495 | -143.2 | 110,000 |
| **117B** | 79,000 | 160,495 | -103.2 | 110,000 |
| **244** | 85,000 | 92,074 | -8.3 | 110,000 |
| **999** | 94,000 | 111,941 | -19.1 | 110,000 |
| **245** | 110,000 | 139,949 | -27.2 | 110,000 |
| **246** | 110,000 | 140,316 | -27.6 | 110,000 |
| **988** | 12,000 | 68,927 | -474.4 | 55,000 |
| **551** | 20,000 | 38,791 | -94.0 | 55,000 |
| **552** | 54,000 | 139,277 | -157.9 | 110,000 |
| **553** | 55,000 | 587,170 | -967.6 | 110,000 |
| **554** | 57,000 | 45,260 | 20.6 | 110,000 |
| **555** | 66,000 | 106,676 | -61.6 | 110,000 |
| **556** | 60,000 | 122,552 | -104.3 | 110,000 |

## ESAL DEVELOPMENT PROCEDURES

The new ESAL table was sorted according to traffic volumes as well as percent commercial vehicles. The segments in each area with the highest volumes or percent vehicles were selected for the purposes of determining whether FHWA class 1-3 vehicles (motorcycles, passenger cars and pick-up trucks) have a significant impact on the overall number of ESALs a segment will experience. It was found that these classes of vehicles may be ignored for the purpose of calculating ESALs. As an example, a 4,000-pound passenger car would generate 0.0004 ESALs. Therefore it would take over 6,000 passenger cars to equal the number of ESALs of one fully loaded FHWA class 9 tractor semi-trailer.

## PROCESS FOR ESAL DISTRIBUTION

The data provided by the TPG and LTPP WIM sites provides the most consistent source of weight data for each vehicle classification. While there is no need to modify the classification sections set up by ADOT, it was important to incorporate the LTPP and TPG WIM sites into the existing classification sections. Tables 5.2 and 5.3 present this information.

Table 5.2. The location of LTPP WIM site relative to ADOT classification stations.

| ADOT Classification Station | Corresponding LTPP WIM Sites |
|---|---|
| 20 | 0214, 1001, 1003, 1006, 1007, 7614 |
| 21 | 1034 |
| 26 | 1037 |
| 29 | 0114 |
| 31 | 1024, 1025, 1062, 1065 |
| 32 | 1002 |
| 46 | 6053 |
| 53 | 1036 |
| 62 | 0501 |
| 75 | 6054 |
| 76 | 1015, 1016, 1017, 1018, 6060 |
| 127 | 6055 |
| 142 | 7079 |
| 148 | 7613 |
| 151 | 0601 |

Table 5.3. The location of ADOT TPG WIM sites relative to ADOT classification stations.

| ADOT Classification Station | Corresponding ADOT TPG WIM Sites |
|---|---|
| 5 | 9006 |
| 21 | 9003 |
| 22 | 9004 |
| 46 | 9001 |

The WIM data passing the QC/QA checks described in chapter 3 was summarized by site to yield yearly average load and percent vehicle truck data. The summaries included percent trucks, average ESALs per truck type, and axle load spectrum. For vehicle class 4-13, a reasonableness check was applied consisting of comparing the average ESALs per class for all years of data to the corresponding ESALs calculated using the maximum legal gross vehicle weights (GVWs) for each class. Table 5.4 summarizes this comparison for flexible pavements.

Table 5.4. ADOT network average ESALs by vehicle class for flexible pavement for all years.

| Vehicle Class | ESALs from WIM Average | ESALs From Maximum GVW* | Standard Deviation of WIM Averages |
|---|---|---|---|
| **4** | 0.81 | 2.3 | 0.397 |
| **5** | 0.20 | 1.9 | 0.122 |
| **6** | 0.66 | 1.5 | 0.354 |
| **7** | 0.53 | 2.3 | 0.288 |
| **8** | 0.59 | 3.2 | 0.439 |
| **9** | 1.29 | 2.4 | 0.532 |
| **10** | 1.25 | 1.8 | 0.707 |
| **11** | 1.76 | 6.1 | 1.083 |
| **12** | 0.96 | 5.7 | 0.644 |
| **13** | 3.06 | 5.4 | 1.334 |

*Note: ESAL table values are based on SN=4 and $P_t$=2.5, using the AASHTO[3] design procedure and 14 kip single unit front axle, 12 kip multiple unit front axle, 20 kip single axle, and 34 kip dual tandem axle weights.

As expected, the average ESALs per class from the WIM sites is less than the ESALs from the estimated maximum GVW. This is because some trucks are empty or carrying a light cargo that fills the truck before loading the truck to the maximum GVW. This is commonly observed and has been thoroughly studied by C. Dahlin of the Minnesota DOT.[4]

Similarly, the ESALs by vehicle class for rigid pavements were also determined (table 5.5). These values are similar to those in table 5.4, but are not exactly the same. The ESALs from maximum gross vehicle weight were not computed (although they would be very similar to those calculated in table 5.4). The pavement type of the LTPP site, not the pavement type in which the sensors themselves are housed, were used to determine whether the pavement was flexible or rigid.

Table 5.5. ADOT network average ESALs by vehicle class for rigid pavement for all years.

| Vehicle Class | ESALs from WIM Average | Standard Deviation of WIM Averages | Two Standard Deviations of WIM Averages |
|---|---|---|---|
| 4 | 0.89 | 0.213 | 0.426 |
| 5 | 0.15 | 0.080 | 0.161 |
| 6 | 1.07 | 0.464 | 0.929 |
| 7 | 2.25 | 1.095 | 2.191 |
| 8 | 0.73 | 0.537 | 1.073 |
| 9 | 2.13 | 0.634 | 1.268 |
| 10 | 1.68 | 0.607 | 1.213 |
| 11 | 1.77 | 0.832 | 1.664 |
| 12 | 0.92 | 0.369 | 0.739 |
| 13 | 4.75 | 1.455 | 2.910 |

An important distinction that needs to be made is that the standard deviation noted in tables 5.4 and 5.5 is the standard deviation of the average values of each WIM site. It is not the standard deviation of all data collected at the sites within the flexible or rigid pavement type groupings.

## COMPARISON OF DATA FROM TWO ADJACENT LTPP WIM SITES

A study was undertaken to determine if similar traffic patterns existed between relatively close WIM sites on a major interstate in Arizona. Two LTPP WIM sites were selected: 041007 and 041006 on westbound I-10 west of Phoenix. The chosen sites were 5 miles apart and LTPP WIM data was collected for the truck lane at both sites.

The comparison results were very encouraging, as most heavy vehicle classes showed little percent difference between the two sites using daily and yearly comparisons. However, two vehicle classes did show differences that triggered further investigation. The vehicle classes of concern were 5 and 8 (see appendix B, daily comparisons). Figure 5.2 shows the comparison between vehicle types for the year 1996.

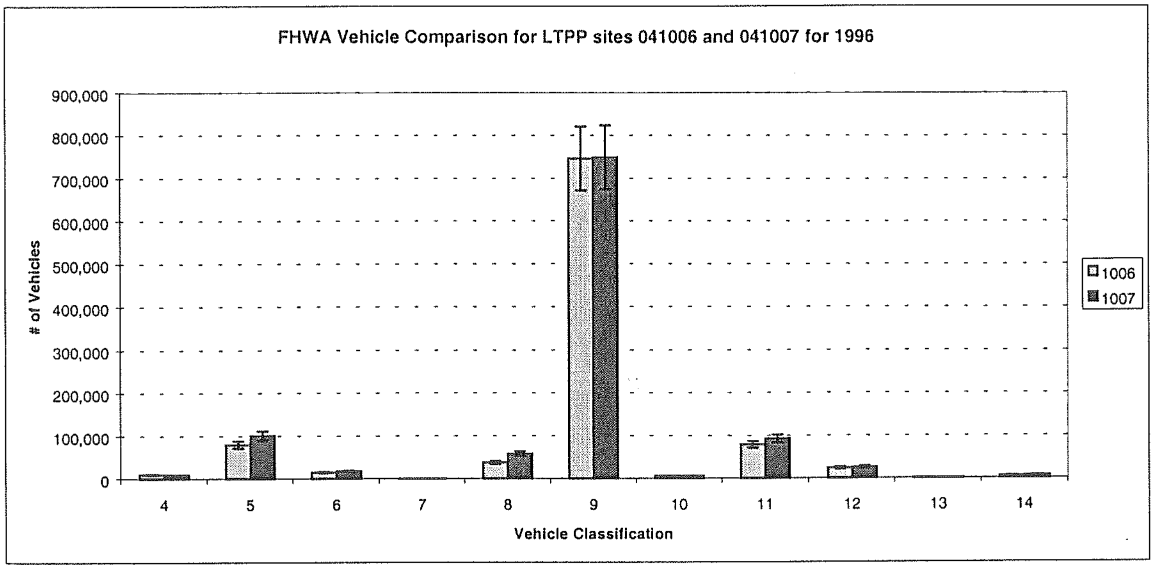



Figure 5.2. Annual comparison of FHWA class 4-13 vehicles between 041006 and 041007.

The experience NCE has gained through processing the Western Region WIM data caused the team to question if the difference was due to Recreational Vehicles (RVs). This suspicion was further fueled by the consistent trend of more vehicle classes 5 and 8 being observed at LTPP site 041007 as compared to site 041006. The team questioned if these vehicles were leaving I-10 and traveling south on SR85. This movement of vehicles was confirmed by ADOT personnel as SR85 is a route to a popular resort destination on the Gulf of Mexico. Further, it was verified by ADOT TPG that the actual number of class 5 and 8 vehicles is much less than what the data shows because the AVC equipment is misclassifying these vehicles based on axle spacing parameters. Other members of TAC stated that a significant number of class 9 vehicles also use the SR855 by-pass, but as can be seen in figure 5.2, this is not shown in the data provided to NCE.

## COMPARITON OF LTPP AND TPG DATA FROM THE SAME CLASSIFICATION STATION

There were two classification stations that have LTPP and TPG AVC/WIM equipment installed: stations 21 and 46. The TPG data for station 21 did not pass the QC/QA analysis, but the data for station 46 did. Unfortunately, there was not any common year between the LTPP and TPG data, but it was possible to compare the annual trends. This comparison is shown in table 5.6. For most classes, the data compares quite well. However, almost 12 percent of the TPG vehicles fell in class 14 (unclassified). In 1998, almost 48 percent of the vehicles fell in class 14, which suggests that the TPG system is in need of calibration (not included in table 5.6).

Table 5.6. Comparison of LTPP and TPG AVC data in station 46.

| | Vehicle Classification (% by Class) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1993 - LTPP | 2 | 15.2 | 1.8 | 0.6 | 3.6 | 68 | 0.3 | 5.8 | 1.7 | 0.2 | 0.8 |
| 1994 - LTPP | 1.7 | 13.3 | 1.8 | 0.6 | 6.7 | 67.3 | 0.4 | 5.5 | 1.6 | 0.4 | 0.6 |
| 1995 - LTPP | 0.9 | 5.7 | 1.1 | 0 | 14.5 | 59.5 | 0.2 | 4.7 | 1.4 | 0.1 | 0.4 |
| 1996 - LTPP | 1 | 14.6 | 1.2 | 0 | 14.9 | 61.1 | 0.3 | 4.9 | 1.3 | 0.2 | 0.4 |
| 1997 - TPG | 1.1 | 14 | 1.7 | 0 | 3.3 | 64.3 | 0.3 | 2.3 | 0.9 | 0.1 | 11.9 |

## COMPARISON OF TPG DATA WITH CONTINUOUS AVC/WIM DATA

Within classification station 151 is an LTPP WIM system where the sensors collect data in all lanes and both directions (typically, the sensors are only in the single lane that contains the LTPP test section). At sites with all lanes instrumented, it is possible to calculate the AADT and percent trucks (which otherwise is impossible without making assumptions about traffic distribution, see appendix B). Table 5.7 shows the results of the comparison between the continuous data collection and the TPG 6-hour manual count for classification and mechanical count for AADT.

Table 5.7. Comparison of AADT and percent trucks between TPG and LTPP data.

| Year | TPG AADT | TPG % Trucks | LTPP AADT | LTPP % Trucks | % Difference AADT | % Difference Trucks |
|---|---|---|---|---|---|---|
| 1994 | 14068 | 31.3 | 12122 | 41.8 | 16 | 25 |
| 1995 | 14304 | 36.4 | 14210 | 40.6 | 0.7 | 10 |
| 1996 | 24900 | 11.5 | 14590 | 42.3 | 71 | 73 |

Between 1995 and 1996, the TPG data changes drastically while there is no such fluctuation in the LTPP data. This highlights the variability inherent in expanding short periods of data collection into annual values.

## GROWTH FACTORS FOR ESAL PER VEHICLE CLASS AND CHANGES IN MAKEUP OF TRUCK TRAFFIC

Observation of the LTPP WIM data has shown that the traffic makeup changes in many ways with time. Change in AADT with time has already been discussed. Two analyses were performed to look at other parameters that also change with time. Namely, the change in the ESAL factors associated with each vehicle class over time and the change in the makeup of the truck traffic over time.

The LTPP data revealed that the ESAL factors calculated from WIM data for each truck classification varies from year-to-year. An investigation was conducted to see if a general trend in the calculated ESAL factors could be established and consequently a recommendation be made on whether to incorporate the trend into the ESAL table. This investigation revealed that although calculated ESAL factors may increase or decrease over time for specific sites, in general, the ESAL factors appear to have remained relatively constant from 1993 through 1997. This is logical as the maximum allowable axle weights have not changed during that period. For this reason, the ESAL factors incorporated into the ESAL table have not been adjusted with time.

In addition, the makeup of the truck traffic also changes over time. It has been found that for the LTPP WIM sites for the years 1993 through 1997, the class 9 truck percentage relative to the total truck traffic has increased in increments of approximately 2.5 percent per year.

$$\% \text{ Class 9 Trucks}_{(n)} = \% \text{ Class 9 Trucks}_{(1993)} + 2.5\% * (\text{Year} - 1993)$$

Note: Percent class 9 trucks in the above equation is relative to the total truck traffic.

Relative to the entire traffic stream, class 9 trucks have increased in increments of approximately 0.8 percent per year.

$$\% \text{ Class 9 Trucks}_{(n)} = \% \text{ Class 9 Trucks}_{(1993)} + 0.8\% * (\text{Year} - 1993)$$

Note: Percent class 9 trucks in the above equation is relative to the total traffic stream.

This issue is worth revisiting in another 3 to 5 years to see if the trend in increasing percentages of class 9 vehicles in the traffic stream is continuing. If it is, consideration should be given to modifying the growth factor by vehicle class.

## INVESTIGATION OF AVC AND WIM CALIBRATION

### Current Practice

As discussed in chapter 3, the ADOT maintains a network of 14 permanent WIM sites, five AVC sites and two additional AVC sites equipped with portable WIM systems (i.e., the sensors are installed permanently, while the data acquisition system is portable). In addition, the Arizona TPG maintains another six WIM sites, plus two AVC sites. These WIM sites are equipped with either bending-plate or piezo-electric sensors and were supplied by either PAT or IRD. The AVC systems come from PAT and they are of the double loop plus axle sensor technology.

The on-site WIM calibration method used is a variation of the method prescribed by the LTPP directive TDP-11 (April 1998).[5] It involves successive passes of two 5-axle semi-trailer (3S-2) test trucks. Typically, these trucks have flat-bed trailers and similar suspension systems in their corresponding axles. The trucks are loaded near their maximum GVW of 80 kips and their axle loads are measured using a static weigh scale.

Initially, 10 runs are performed at a given speed, which is selected depending on the speed limit at a WIM site. For these runs, errors are calculated as the percent difference between the static load and the WIM measurements for each of the:

- Steering axle.
- First tandem axle .
- Second tandem axle.
- GVW.

The statistics calculated are the average and the standard deviation of the percent errors for each of these four groups of measurements. A WIM system must yield average errors lower than a prescribed level in each of these four groups of measurements in order to pass. These levels of average error are set at +-5 percent for the bending plate systems and at a slightly higher value for the piezo systems. If during this process, consistent trends emerge in the average errors, calibration adjustments are made to the WIM system. Once the calibration is completed and if the maximum average errors are not exceeded, additional runs are performed using the same two trucks running at various speeds, to verify that the average WIM errors remain within the prescribed range. Otherwise, the particular WIM site is "shut-down" and no further data is collected from it until it can be fixed. This calibration process takes about 2-3 hours per WIM site to complete.

The statewide WIM data is post-processed at the office for quality assurance using the methodology developed by Minnesota DOT (TRR 1364, 1994).[(4)] For this purpose, the consistent properties of the steering axle load of 3-S2 trucks is used, rather than the consistent properties in the distribution of their GVW. In addition, the WIM data collected for the LTPP sites is processed through the software package developed by Chaparral Inc, which encompasses a wider range of QA tests than the Minnesota DOT method.

The on-site calibration of AVC systems is done through visual inspection without a rigorous analysis of observed versus recorded vehicle classification data. No post-processing of the AVC data is carried out for QA purposes.

## Recommended Improvements

A number of recommendations are made for improving and expediting the ADOT WIM and AVC calibration procedures. These include considering the effect of pavement roughness and vehicle speed on WIM error analysis and using a video recorder for AVC calibration, respectively.

### *Improved WIM Calibration Method*

It is well documented that the variation in dynamic axle loads increases with speed and roughness, hence affecting the magnitude of the WIM errors observed at a given site. Experimental evidence (Papagiannakis et al., 1990)[(6)] has produced relationships that can be used to calculate the expected coefficient of variation (CV percent) of dynamic axle loads as a function of pavement roughness (R in terms of International Roughness Index (IRI) m/km)) and vehicle speed (V in m/km). These relationships are plotted on figures 5.3 through 5.5 in terms of the CV of dynamic load versus the vehicle speed for three levels of pavement roughness (i.e., smooth, medium and high roughness). The two suspension types referred to in these figures are a rubber-sprung walking beam and an independent air-ride, which represent extremes in dynamic behavior (i.e., a leaf spring would exhibit a dynamic load CV between the two shown). It should be evident that using test trucks with air-ride suspensions would reduce the dynamic load variation and expedite the calibration process.

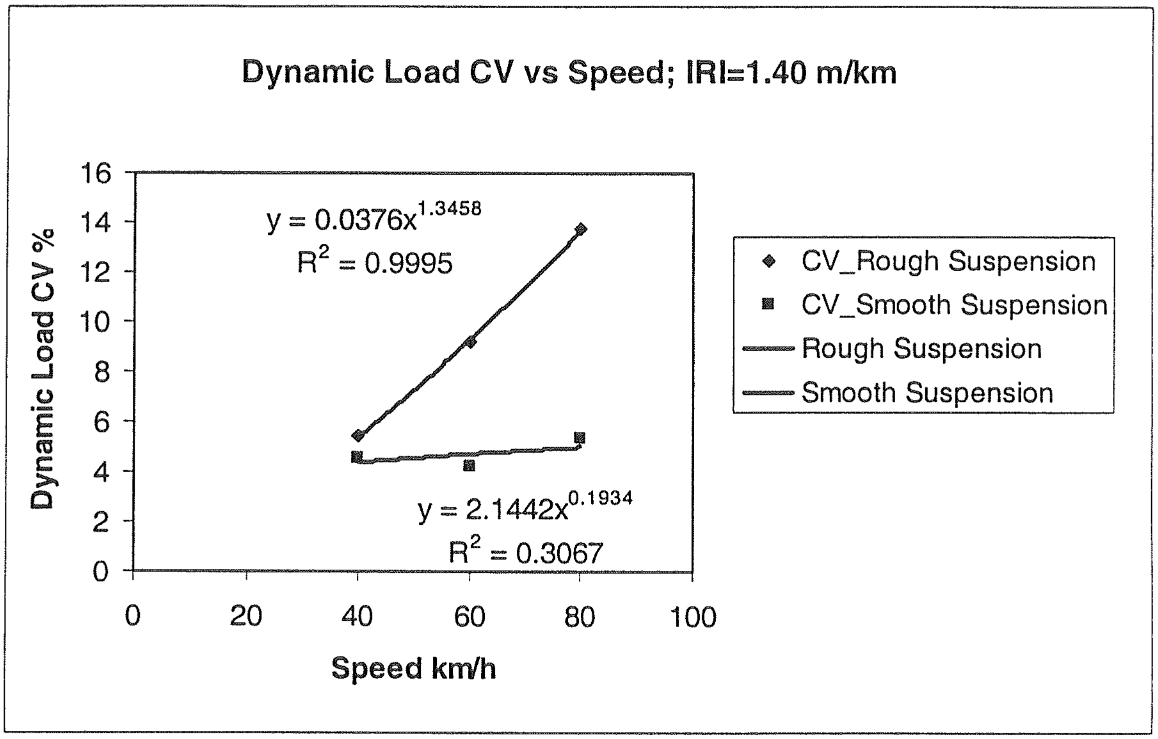



Figure 5.3. Dynamic load vs. vehicle speed; IRI=1.40 m/km.

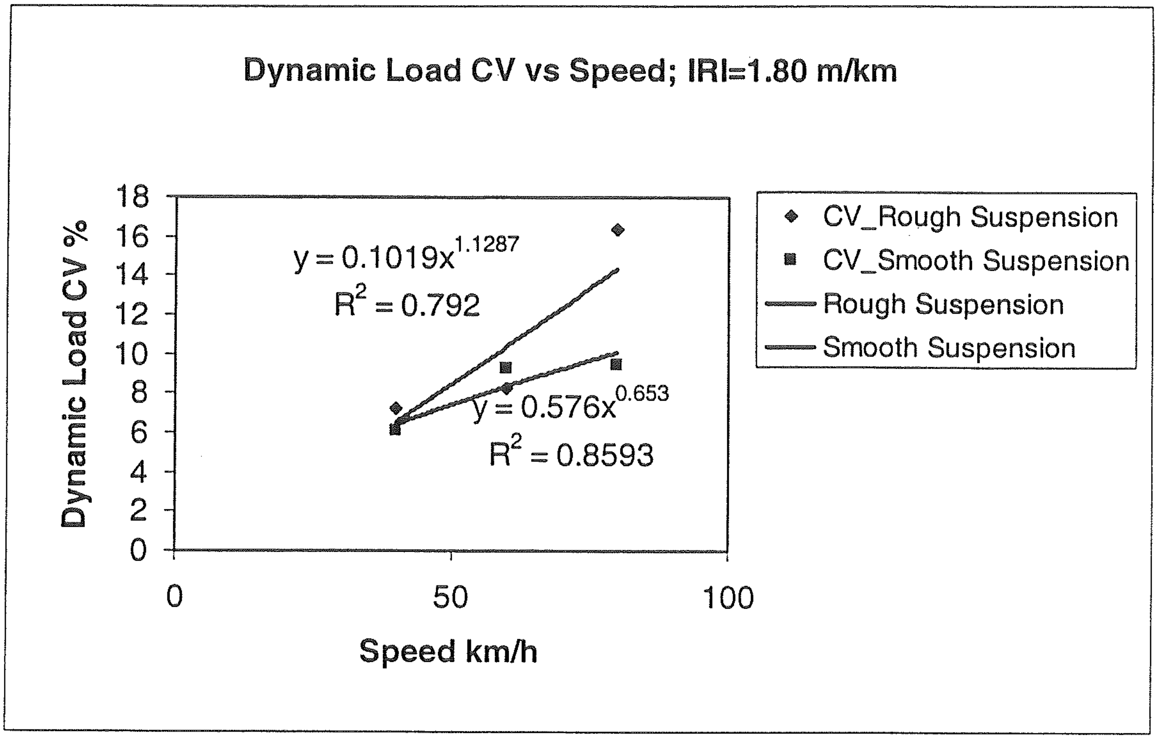



Figure 5.4. Dynamic load vs. vehicle speed; IRI=1.80 m/km.

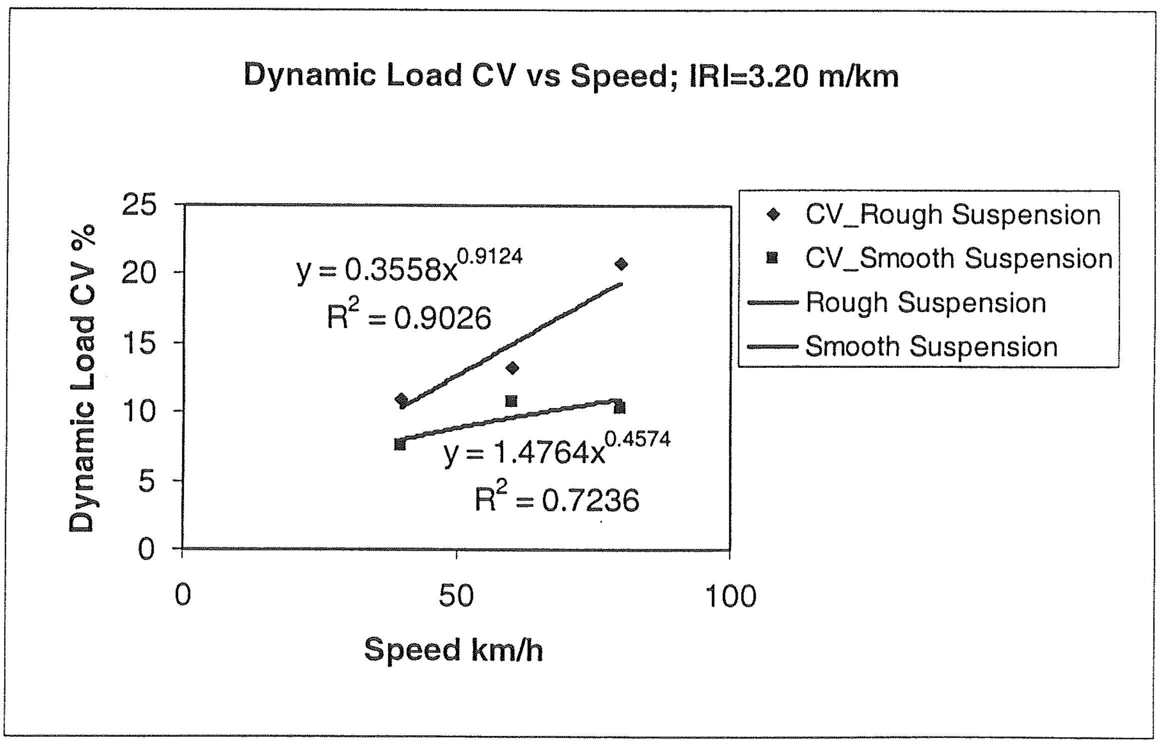



Figure 5.5. Dynamic load vs. vehicle speed; IRI=3.20 m/km.

Another experimental observation is that replicate test truck passes (i.e., same truck and speed) generate repetitive dynamic axle loads along the road. Hence, the magnitude of the dynamic axle loads applied on a WIM sensor from successive replicate truck passes are equal. This allows reducing the number of test truck passes for achieving an initial WIM calibration. To take advantage of this properties, it is suggested to carry out an initial analysis of the results by axle or axle group (i.e., tandems or triples) rather than by averaging the errors. This procedure is explained below.

These findings allow the following calibration approach (after Papagiannakis et. al, 1996).[7]

1. Calculate the anticipated range in the WIM measurements for each axle/axle group as the mean (i.e., static) load +- 2 standard deviations (i.e., calculated as the static load value multiplied by the CV obtained from figures 1 through 3 for the roughness at the site and the speeds of the test vehicles). This can be easily done at the office for all the speeds expected to of the test trucks at the site, given its IRI roughness.

2. Perform one run of each test truck and compare the WIM measurements of each axle/axle group and each vehicle to their anticipated range. There are four distinct possibilities:

    a. If all measurements fall outside the anticipated range and they are all either higher or lower than this range, adjust system calibration calculated as:

$$calibration\ \ factor\ \ adjustment = \frac{\sum static_i}{\sum WIM_i}$$

    It would be desirable to carry out this adjustment prior to continuing with subsequent test runs.

    b. If all measurements fall outside the anticipated range and some are above, while other below, there are major problems with the WIM system, either software (e.g., integration algorithms of piezo signals) or hardware (e.g., damaged strain gauges of bending plates. These problems are not likely to be solved through calibration adjustments and will require a technician's intervention.

    c. If all measurements fall within their anticipated ranges, no calibration adjustments are necessary prior to carrying a subsequent test run by repeating step 2.

    d. If some measurements are outside their expected range, while others are inside, a judgement call must be made whether actions corresponding to either (a) or (c) are to be taken.

3. Once the desirable number of runs is carried out and condition (2c) is satisfied for all runs and all speeds, it should be ensured that the requirements of the TDP 11 Protocol are met, that is average WIM errors are lower than the prescribed value percent for each axle group (i.e., steering, first tandem and second tandem) for all test speeds.

In summary, this approach allows expedient (i.e., several test runs) determination of whether a WIM calibration problem exists and whether the problem can be solved via calibration factor adjustments or there is a hardware/software problem present.

*Improved WIM Data QA Method for Non-LTPP Sites*

In improving the WIM data QA for non-LTPP sites, it is advised to use the properties of the traffic stream to determine likely problems with the data. The simplest approach is to use the steering axle load of the three-S2 trucks as an indicator of WIM data quality. This is one of the tests used by the Minnesota DOT approach and does not take into account problems with the vehicle classifying algorithms of WIM systems. It has nevertheless been used successfully as a QA criterion (Ott et al., 1996)[(8)] and it is used by a number of WIM manufacturers as a means of auto-calibrating WIM systems. In establishing mean and standard deviation values for the steering axles of three-S2 trucks, it is advised to collect a small data sample at static weigh scales (e.g., 10-20 trucks per season). Suggested static load locations are the major ports of entry at the four boundaries of the State. It is understood that the ports of entry truck inspection stations run independently of ADOT. However, it would take a small effort to convince them to print and retain the small sample size required.

*Improved AVC Calibration Method*

As described next, AVC data collection should complement the WIM data collection for the purpose of predicting AADT volumes and accumulated ESALs. For this purpose, it is essential that AVCs are properly calibrated. It is recommended to use a video camera for recording the vehicle classification of the traffic stream, instead of relying on visual observations. This can be done using a household-grade video camera set on a tripod on the side of the road. The clock on the camera can be synchronized with the clock on the AVC system. Even recording over a short period of time (e.g., while visiting an AVC site) would allow a far more accurate calibration of the AVCs than as compared with visual observation. The data should be post-processed at the office by at least two observers and the manual classification procedure compared to the AVC to decide on its accuracy.

## SURVEY OF OTHER AGENCIES

For comparative purposes, a number of State Highway Agencies were surveyed to determine how they calculated ESALs. The survey was submitted to 15 agencies and 11 responded. The following questions were included in the survey:

*1. Does your State use ESAL computations for pavement design and rehabilitation?*

*Yes:____*
*No:_____*

*2. What type of types of data do you use to come up with the ESAL table values? (Will you fax us the first page of your ESAL table for an example?)*

*a.) Do you use a single ESAL table for all design locations within your state or is a different ESAL value computed for different locations based upon load information for that location?*

*3. Do you break down ESALs by vehicle classification*

*4. Do you apply average ESAL factors to the vehicles in each classification? What are they?*

*5. Do you use growth factors to expand ESALs to design years?*

*6. Do you use WIM data? If not, what do you use for load data?*

*7. Are there links between Pavement Management System (PMS) data and the ESAL tables?*

*a.) Are your growth factors for PMS the same for ESAL growth factors?*

*8. How much confidence do you have in the values you use for pavement design and rehab?*

*Survey States comments if any:*

The complete responses to these surveys can be found in appendix C, but the results have been summarized in table 5.8.

Every agency that responded said that they did use ESAL computations. However, in reviewing table 5.8, that is about the only thing they all had in common. On the whole, most States use WIM data as a method of determining or confirming ESAL values for different vehicle types, and use different ESAL values for different locations. The level of confidence in the resulting values ranged from fair to high. The project team found the methodology employed by Kentucky of particular interest. As mentioned previously, the detailed response from each agency can be found in appendix C.

Table 5.8. Summary of agency responses to ESAL survey.

| | Washington | Kansas | Oklahoma | Idaho | Oregon | South Dakota | Montana | Wyoming | Utah | Nebraska | Kentucky |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Question 1 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Question 2 | * | * | * | * | * | * | Static scale data | * | Axle weights from WIM | * | * |
| Question 2a | Different | Different | * | Different | Same | Different | Same | Same | Different | Different | Different |
| Question 3 | Y | Y | N | N | Y | Y | Y | Y | Y | Y | N |
| Question 4 | Y | Y | Y | N | Y | N | Y | Y | Y | Y | Y |
| Question 5 | Y | N | N | Y | Y | Y | Y | Y | N (for volumes, not ESALs) | Y | Y |
| Question 6 | Y and N | Y | N | Y | N | Y | N (but will be changing) | Y | Y | Y | Y |
| Question 7 | Y | N | N | * | Y | N | N | Y | Y | * | N |
| Question 7a | Y | * | N | * | Y | * | * | N | * | * | * |
| Question 8 | High--ESAL (60-75%--traffic) | Fairly good | High | Good | Fairly good | Depends on proximity to WIM site | Average to high | Fair | High on major routes, lower on other routes | Good | High |

*No comments provided.

# CHAPTER 6: PREPARE NEW ESAL DESIGN TABLES

This chapter describes the format of the new ESAL tables, including the relevant analyses. A complete Users Manual can be found in appendix D.

## DATA INPUTS

Three electronic files provided by the Arizona TPG were implemented into the ESAL design tables. Information from these files was supplemented by data collected at the LTPP and TPG AVC and WIM sites. The first file was *TR9397C.xls.*, which contains detailed segment location information, the number of lanes for each segment and the AADT and percent commercial vehicle values for each segment from 1993 through 1997. The second file was *Vcls9704.xls*, which contains classification station location data and the break down of the percent of each vehicle class 1-13 for each station to be applied to the 1997 data. The third file was *trfc7497.xls*, which contains the segment location information and the AADT value for each segment dating back to 1974.

The LTPP WIM data was extracted from the Western Regional Information Management System (RIMS) for all years through 1997. A number of investigations into this data were performed as described in chapter 5, including: comparing WIM data from adjacent systems near Phoenix; determining average ESAL factors per vehicle, per segment, and per pavement type; and calculating growth factors for ESALs.

Data was submitted from the four TPG functional WIM sites in Arizona for the years of 1997 and 1998 (except for site 9003, S.R. 95 MP 115EB, for which only 1998 data is available). All four sites are equipped with IRD piezo cable systems. This data was processed using the traffic software developed in the LTPP Program following the same methodologies used to process the data collected at LTPP sites.

As the WIM sensors were in the LTPP test lane, the above data only applied to the test lane. Truck classification as a percentage of total trucks was calculated and then, truck type as a percentage of total traffic was calculated for the test lane using the provided data.

As previously discussed, tables 5.3 and 5.4 show the AVC/WIM systems that were contained in each classification station. In instances where the relationship was 1:1, the TPG values for percent trucks in vehicle classes 4-13 (from *Vcls9704.xls*) were replaced with the values from the AVC/WIM systems. For the classification stations within which multiple AVC/WIM systems were located, the AVC/WIM data was averaged and then replaced the data from *Vcls9704.xls*.

ESAL values for each station were determined in similar fashion. Stations within which WIM systems were located had either the average values of all systems or the distinct values from the one system applied to determine the ESALs per vehicle class 4-

13. For classification stations in which no WIM systems were located, the average values for flexible and rigid pavements (tables 5.5 and 5.6) were utilized.

A table was developed listing the types of data collected at the various segments designated in the existing ESAL table. Particular attention was paid to those segments that contained a WIM system. The factor group for each segment containing a WIM system was determined.

## KEY ASSUMPTIONS

The goal in the development of the ADOT ESAL tables is to report the most accurate forecast of the traffic and axle loading on the ADOT roadway network. There are, however, limitations due to the type of traffic data collection and limited traffic data collection locations. The following are assumptions that the NCE team made during the development of the new ADOT ESAL tables.

### Directional Split

An assumption concerning ADOT traffic data is the directional split of traffic. The assumption is that there is a 50/50 split in traffic (i.e., that the same number of vehicles are traveling in one direction as the other). If this is not the case, then an alteration to the ESAL table spreadsheet can be made to accommodate site-specific information. However, no data that could be used to determine the directional split was provided to the NCE team.

### Necessary Pavement Structure Assumptions

The LTPP WIM data utilizes the site-specific pavement structure for calculating the average ESALs per vehicle type. The ESAL values can vary depending on differences in the pavement type and structural section of each ADOT segment. This difference can be observed for the same axle weight but for different pavement types, (i.e., flexible and rigid pavement) and terminal serviceabilities, as shown in figure 6.1.

It is clear from figure 6.1 that the thickness of the pavement structure has a small effect on the ESAL calculation regardless of pavement type, and using a terminal serviceability of 3.0 instead of 2.5 has a similarly small effect. However, pavement type (portland cement concrete (PCC) or asphalt concrete (AC)) has a significant impact on ESAL calculation. The new ESAL table provides ESAL values for both PCC and AC pavements based on the average ESAL per vehicle class calculated using the 1993 through 1997 LTPP WIM data. In the new ESAL table, ESAL values for both AC and PCC type pavements are provided for each segment based on the recommendation of the TAC.

The TAC requested that the project team investigate the impact of a condition of terminal serviceability of 3.0 instead of 2.5. This was performed and it was determined that at the legal load limits, there is very little difference. As loading increases past the legal limit, the ESALs are slightly less for the calculation based on 3.0 for both rigid and flexible pavements. The relationship is not linear and increases with load (see figures 6.2 and 6.3).

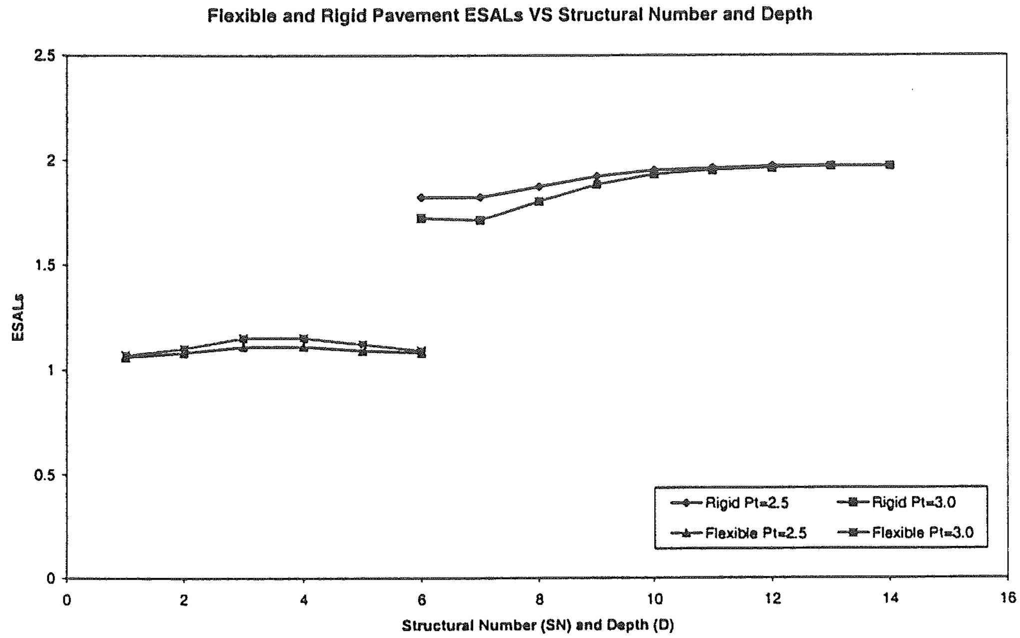



Figure 6.1

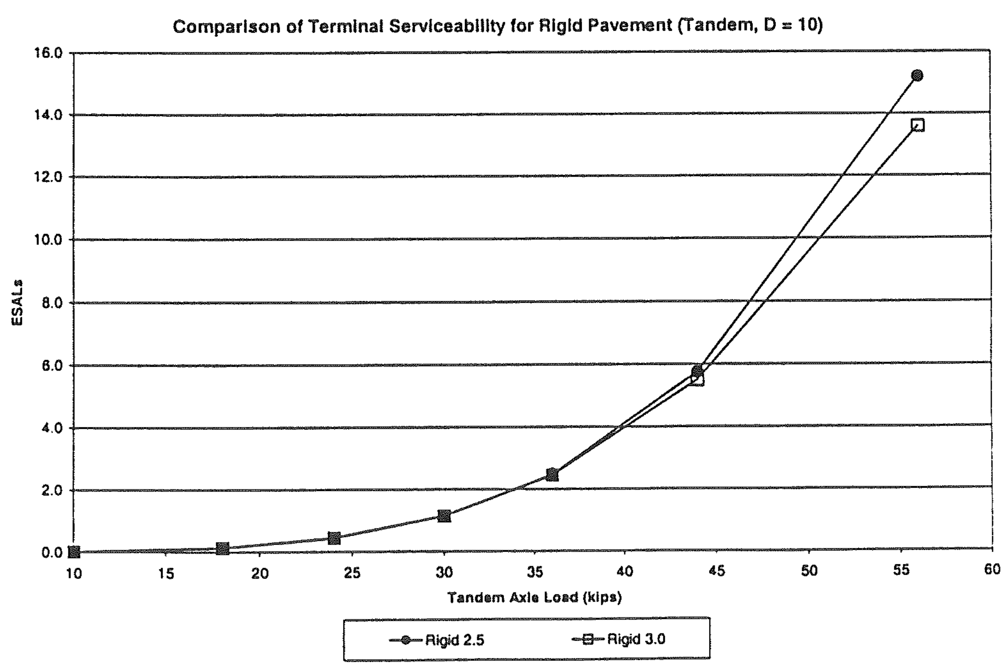



Figure 6.2

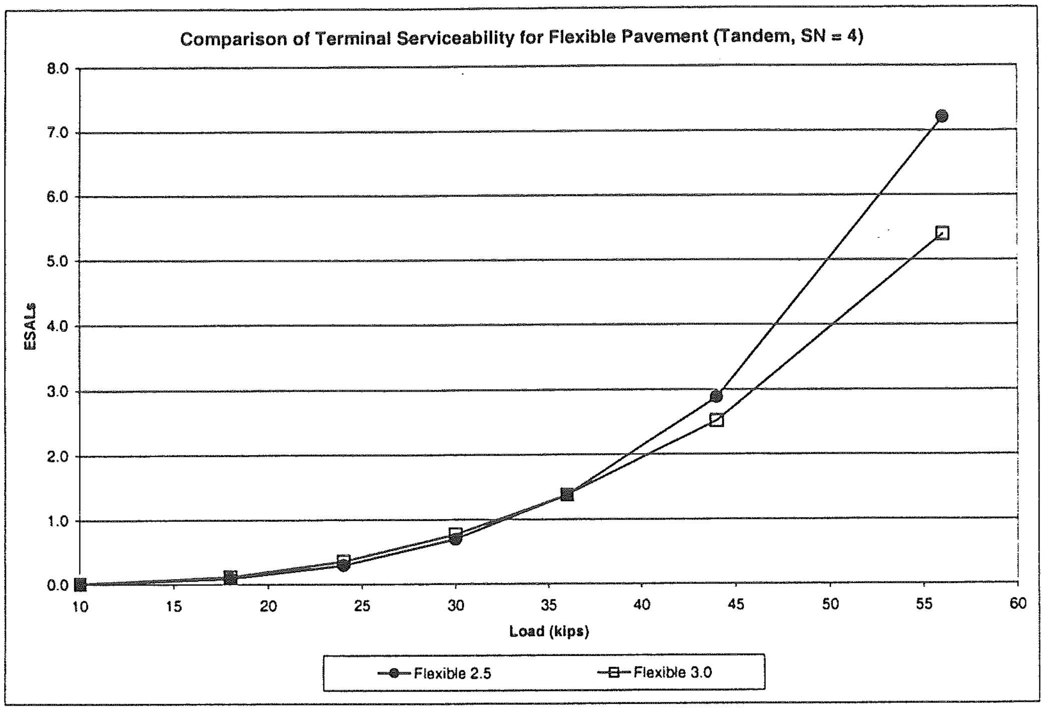



Figure 6.3.

# ESAL TABLES

## Proposed Format for the New ADOT ESAL Tables

Three independent tables were developed for use by ADOT. The new ESAL tables each contain 14 sub-tables in total. The only difference between each table is the set of values used for the ESAL per vehicle class.

- *Average_ESAL_Table.xls* uses either the measured or the averaged ESAL values for classes 4-13 as described in the Data Inputs section.
- *ESAL_Table_One_Std_Dev.xls* uses the measured or averaged values, plus one standard deviation of the averages for each vehicle class.
- *ESAL_Table_Two_Std_Dev.xls* uses the measured or averaged values, plus two standard deviations of the averages for each vehicle class.

Some tables represent calculations and others represent the input location of ADOT TPG and WIM data. This format of table interaction will allow the ESAL tables to be used for years to come, and allow easy access of information necessary for traffic engineering, traffic planning, and pavement design. Appendix F contains a stand-alone document that should be used to navigate through the spreadsheets. The following is a brief description of important elements in the new ESAL table.

*Site Information*

This data (primarily taken from *TR9397C.xls*) contains the segment by segment location, AADT and percent commercial vehicle information.

*Cumulative One-way Flexible KESALs*

This worksheet contains the cumulative thousands of ESALs (KESALs) for each segment assuming that the pavement is flexible. These values are determined by adding the previous year's KESAL total to the KESAL data for a particular year. Cumulative values are calculated through the year 2020. This worksheet is different for the three tables.

*Cumulative One-way Rigid KESALs*

This worksheet contains the cumulative thousands of ESALs (KESALs) for each segment assuming that the pavement is rigid. These values are determined by adding the previous year's KESAL total to the KESAL data for a particular year. Cumulative values are calculated through the year 2020. This worksheet is different for the three tables.

*AADT 1974-2020*

This worksheet contains the AADT values provided by the TPG from 1974 through 1997 (from *trfc7497.xls*). The average percent growth factor is calculated using the methodology described in chapter 5, and in instances where the percent growth is less than 2 percent, it is adjusted to be 2 percent. Using this growth factor, the AADTs from 1998 to 2020 for each segment are calculated. No limit as to maximum growth factor was utilized.

*Capacity*

This worksheet contains a simple logic check as to whether each segment has reached its capacity based on the following assumptions:

Using the 1994 Highway Capacity Manual, the capacity for each segment was calculated. Because capacity is primarily an issue in urban areas, the assumptions were based on urban conditions. Following the equation:

capacity = 2200 vehicles per lane per hour/.08 = 27,500 vehicles per lane per day

As the number of lanes for each segment is known, the capacity was determined for each segment for each year through 2020 (this is contained in the worksheet Total Theoretical Capacity). If a segment is under capacity for a given year, the capacity worksheet will contain the word "pass." If it is at or over capacity, it will contain the word "fail." After discussing the issue of capacity with the TAC, this method was adopted so that capacity issues could be identified but future calculations are based on the assumption that additional lanes will be constructed to handle the additional traffic.

*Rigid KESAL One-way*

This worksheet contains the calculation of rigid KESALs for each segment for each year beginning with 1997. This calculation is described below.

*Rigid ESALs*

This worksheet contains the ESAL factors for vehicle classes 4-13 for each segment, assuming that the pavement is rigid.

*Flexible KESAL One-way*

This worksheet contains the calculation of flexible KESALs for each year beginning with 1997. This calculation is described below, and includes, as instructed by the TAC, a multiplier of 1.1 for the ESALs per vehicle for classes 9-13. This multiplier is a safety factor to account for potential increases in tire pressure and vehicle weights.

*Flexible ESALs*

This worksheet contains the ESAL factors for vehicle classes 4-13 for each segment, assuming that the pavement is flexible.

*Standard Deviation of ESALs per Class*

This worksheet contains the average, plus one and plus two standard deviation values for flexible and rigid pavements. These values are the same as given in tables 5.5 and 5.6.

*AADT Percent Growth for All Years*

This worksheet contains the percent growth from year-to-year for each segment beginning in 1974 and continuing through 2020.

*Number of Lanes*

This worksheet contains the number of lanes in each segment. This value is given for each year between 1997 and 2020 to allow ADOT to evaluate the construction of additional lanes in future years.

*Percent of Each Vehicle Type*

This worksheet contains the percentage of each vehicle class 4-13 for each segment as determined in the most recent year this data was measured (1997).

*ESAL Calculation*

The site specific AADT is the basis or calculating ESALs for the ADOT ESAL table. To this, the nearest classification site/WIM site data available is applied to calculate yearly ESALs. The calculation of the values for rigid ESALs reported in the ESAL tables are done in the following manner using equation 1.

(equation 1)

$$\text{Yearly ESAL}_{seg} = 0.5 * (\text{AADT}_{seg}) * (365) * (\%\ \text{Trucks})*[(\%\ \text{VC4})*(\text{ESAL4}) + (\%\text{VC5}) * (\text{ESAL5}) + \ldots\ldots.. + (\%\ \text{VC13}) * (\text{ESAL13})]$$

The definitions of the variables for equation 1 are as follows:

| | |
|---|---|
| $\text{ESAL}_{seg}$: | Total yearly one-way ESALs for all lanes for a network segment. |
| $\text{AADT}_{seg}$: | Average Annual Daily Traffic collected by ADOT for the total two-way traffic for all lanes for a single network segment. |
| % Trucks: | Percentage of trucks in the traffic system. |
| %VC(#): | This is the percent of vehicle class (4-13) in the truck lane determined from collected WIM data. |
| ESAL(#): | This is the average ESAL of vehicle class (4-13) in the truck lane determined from collected WIM data. |

In order to calculate the flexible ESAL values, an additional factor of 1.1 is used as a multiplier within the brackets for vehicle classes 9-13 as shown in equation 2. This 1.1 multiplier was suggested by ADOT TAC as a safety factor to account for potential increases in tire pressure and vehicle weights. The KESAL values are determined by dividing the $\text{ESAL}_{seg}$ value by 1000.

(equation 2)

$$\text{Yearly ESAL}_{seg} = 0.5 * (\text{AADT}_{seg}) * (365) * (\%\ \text{Trucks})*[(\%\ \text{VC4})*(\text{ESAL4}) + (\%\text{VC5}) * (\text{ESAL5}) + \ldots\ldots.. + 1.1 * (\%\ \text{VC9}) * (\text{ESAL9}) + 1.1 * (\%\ \text{VC10}) * (\text{ESAL10}) + \ldots\ldots.. + 1.1 *(\%\ \text{VC13}) * (\text{ESAL13})]$$

## COMPARISON OF CURRENT AND NEW ESAL TABLES

As a test of the new ESAL table, the 1997 and 2017 AADT values and cumulative ESALs were compared with the same values from the existing ADOT ESAL table. This comparison was carried out for 20 segments, the 10 with the highest AADT values and the 10 with the lowest AADT values. Table 6.1 contains the results of the AADT comparison and tables 6.2 and 6.3 contain the results of the cumulative ESAL comparison for flexible and rigid pavements, respectively.

Table 6.1. AADT comparison between current and new ESAL tables.

| Order | Segment | Existing ESAL Table AADT, 1997 | New ESAL Table AADT, 1997 | Existing ESAL Table AADT, 2017 | New ESAL Table AADT, 2017 | % Difference in Reported 1997 AADT | % Difference in Reported 2017 AADT |
|---|---|---|---|---|---|---|---|
| 1L | 719 | 264 | 74 | 317 | 104 | 72.0 | 67.2 |
| 2L | 873 | 166 | 95 | 226 | 717 | 42.8 | -217.3 |
| 3L | 874 | 188 | 105 | 256 | 2575 | 44.1 | -905.9 |
| 4L | 1160 | 212 | 125 | 254 | 980 | 41.0 | -285.8 |
| 5L | 528 | 139 | 129 | 167 | 190 | 7.2 | -13.8 |
| 6L | 882 | 160 | 161 | 218 | 225 | -0.6 | -3.2 |
| 7L | 762 | 186 | 172 | 223 | 430 | 7.5 | -92.8 |
| 8L | 819 | 260 | 175 | 426 | 245 | 32.7 | 42.5 |
| 9L | 799 | 254 | 227 | 305 | 344 | 10.6 | -12.8 |
| 10L | 798 | 223 | 246 | 267 | 318 | -10.3 | -19.1 |
| 1H | 68 | 205186 | 208643 | 400000 | 292100 | -1.7 | 27.0 |
| 2H | 72 | 153672 | 209066 | 276610 | 589642 | -36.0 | -113.2 |
| 3H | 66 | 192487 | 209166 | 400000 | 367014 | -8.7 | 8.2 |
| 4H | 76 | 212000 | 210332 | 381600 | 294465 | 0.8 | 22.8 |
| 5H | 73 | 189426 | 214944 | 340967 | 426763 | -13.5 | -25.2 |
| 6H | 74 | 192197 | 217255 | 345955 | 430377 | -13.0 | -24.4 |
| 7H | 67 | 192487 | 218411 | 400000 | 455807 | -13.5 | -14.0 |
| 8H | 1004 | 189384 | 221336 | 340891 | 540334 | -16.9 | -58.5 |
| 9H | 75 | 195396 | 223033 | 351713 | 441675 | -14.1 | -25.6 |
| 10H | 69 | 202260 | 231123 | 400000 | 984575 | -14.3 | -146.1 |

Table 6.2. Cumulative ESAL comparison between current and new ESAL tables for flexible pavements.

| Order | Segment | New ESAL Flex Average + 2 StDev ESAL, 2017 | % Diff. in Reported 1997 Flexible ESALs | % Diff. in Forecasted 1997 Average + 1 StDev Flexible ESALs | % Diff. in Forecasted 1997 Average + 2 StDev Flexible ESALs | % Diff. in Forecasted 2017 Average Flexible ESALs | % Diff. in Forecasted 2017 Average + 1 StDev Flexible ESALs | % Differ. in Forecasted 2017 Average + 2 StDev Flexible ESALs |
|---|---|---|---|---|---|---|---|---|
| 1L | 719 | 15 | 99.1 | 98.3 | 95.7 | 99.2 | 98.5 | 97.9 |
| 2L | 873 | 485 | 60.0 | 20.0 | 0.0 | -23.5 | -104.7 | -185.3 |
| 3L | 874 | 1600 | 50.0 | 33.3 | 0.0 | -261.5 | -497.4 | -733.3 |
| 4L | 1160 | 428 | 71.4 | 57.1 | 28.6 | 14.2 | -43.9 | -101.9 |
| 5L | 528 | 68 | 50.0 | 0.0 | -50.0 | 60.6 | 32.4 | 4.2 |
| 6L | 882 | 231 | 0.0 | -75.0 | -125.0 | 8.3 | -51.4 | -111.9 |
| 7L | 762 | 663 | -133.3 | -333.3 | -500.0 | -174.7 | -372.7 | -569.7 |
| 8L | 819 | 89 | 80.0 | 40.0 | 20.0 | 76.6 | 60.1 | 43.7 |
| 9L | 799 | 325 | -50.0 | -125.0 | -225.0 | -2.9 | -70.1 | -137.2 |
| 10L | 798 | 352 | -50.0 | -150.0 | -250.0 | -27.5 | -110.8 | -193.3 |
| 1H | 68 | 191815 | 24.8 | -26.1 | -76.9 | 38.9 | -2.5 | -43.8 |
| 2H | 72 | 305953 | -0.6 | -68.6 | -136.6 | -30.2 | -118.2 | -206.3 |
| 3H | 66 | 220712 | 19.6 | -34.7 | -89.0 | 25.0 | -25.7 | -76.4 |
| 4H | 76 | 193368 | 26.6 | -23.0 | -72.6 | 40.3 | 0.0 | -40.3 |
| 5H | 73 | 245812 | 16.1 | -40.7 | -97.4 | 15.1 | -42.2 | -99.6 |
| 6H | 74 | 248028 | 16.4 | -40.1 | -96.6 | 15.6 | -41.5 | -98.5 |
| 7H | 67 | 258266 | 16.1 | -40.6 | -97.4 | 12.2 | -47.1 | -106.4 |
| 8H | 1004 | 291765 | 13.5 | -44.9 | -103.3 | -0.8 | -68.9 | -137.0 |
| 9H | 75 | 254623 | 15.6 | -41.5 | -98.6 | 14.8 | -42.8 | -100.4 |
| 10H | 69 | 465686 | 15.5 | -41.7 | -98.8 | -50.6 | -152.4 | -254.2 |

Table 6.3. Cumulative ESAL comparison between current and new ESAL tables for rigid pavements.

| Order | Segment | Existing ESAL Rigid ESAL, 1997 | New ESAL Rigid Average ESAL, 1997 | New ESAL Rigid Average + 1 StDev ESAL, 1997 | New ESAL Rigid Average + 2 StDev ESAL, 1997 | Existing ESAL Rigid ESAL, 2017 | New ESAL Rigid Average ESAL, 2017 | New ESAL Rigid Average + 1 StDev ESAL, 2017 | New ESAL Rigid Average + 2 StDev ESAL, 2017 | % Diff. in Reported 1997 Rigid ESALs | % Diff. in Forecasted 1997 Average + 1 StDev Rigid ESALs | % Diff. in Forecasted 1997 Average + 2 StDev Rigid ESALs | % Diff. in Forecasted 2017 Average Rigid ESALs | % Diff. in Forecasted 2017 Average + 1 StDev Rigid ESALs | % Diff. in Forecasted 2017 Average + 2 StDev Rigid ESALs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1L | 719 | 26 | 0.3 | 0.4 | 1 | 798 | 8 | 11 | 15 | 98.8 | 98.5 | 96.2 | 99.0 | 98.6 | 98.1 |
| 2L | 873 | 6 | 3 | 4 | 5 | 190 | 270 | 369 | 467 | 50.0 | 33.3 | 16.7 | -42.1 | -94.2 | -145.8 |
| 3L | 874 | 7 | 3 | 5 | 6 | 215 | 893 | 1217 | 1540 | 57.1 | 28.6 | 14.3 | -315.3 | -466.0 | -616.3 |
| 4L | 1160 | 8 | 3 | 3 | 4 | 238 | 232 | 317 | 402 | 62.5 | 62.5 | 50.0 | 2.5 | -33.2 | -68.9 |
| 5L | 528 | 3 | 1 | 2 | 2 | 80 | 34 | 48 | 63 | 66.7 | 33.3 | 33.3 | 57.5 | 40.0 | 21.3 |
| 6L | 882 | 4 | 5 | 7 | 9 | 122 | 129 | 175 | 222 | -25.0 | -75.0 | -125.0 | -5.7 | -43.4 | -82.0 |
| 7L | 762 | 4 | 9 | 13 | 17 | 111 | 334 | 479 | 623 | -125.0 | -225.0 | -325.0 | -200.9 | -331.5 | -461.3 |
| 8L | 819 | 6 | 2 | 3 | 3 | 177 | 45 | 64 | 82 | 66.7 | 50.0 | 50.0 | 74.6 | 63.8 | 53.7 |
| 9L | 799 | 5 | 7 | 10 | 12 | 153 | 181 | 247 | 313 | -40.0 | -100.0 | -140.0 | -18.3 | -61.4 | -104.6 |
| 10L | 798 | 4 | 8 | 11 | 13 | 134 | 197 | 268 | 339 | -100.0 | -175.0 | -225.0 | -47.0 | -100.0 | -153.0 |
| 1H | 68 | 4819 | 4176 | 5766 | 7357 | 149400 | 105231 | 145316 | 185400 | 13.3 | -19.7 | -52.7 | 29.6 | 2.7 | -24.1 |
| 2H | 72 | 3609 | 4184 | 5778 | 7372 | 111892 | 167848 | 231785 | 295722 | -15.9 | -60.1 | -104.3 | -50.0 | -107.2 | -164.3 |
| 3H | 66 | 4521 | 4186 | 5781 | 7376 | 140154 | 121084 | 167208 | 213331 | 7.4 | -27.9 | -63.1 | 13.6 | -19.3 | -52.2 |
| 4H | 76 | 4979 | 4210 | 5813 | 7417 | 154361 | 106083 | 146492 | 186901 | 15.4 | -16.8 | -49.0 | 31.3 | 5.1 | -21.1 |
| 5H | 73 | 4449 | 4302 | 5941 | 7579 | 137925 | 134854 | 186223 | 237592 | 3.3 | -33.5 | -70.4 | 2.2 | -35.0 | -72.3 |
| 6H | 74 | 4514 | 4348 | 6005 | 7661 | 139942 | 136100 | 187943 | 239786 | 3.7 | -33.0 | -69.7 | 2.7 | -34.3 | -71.3 |
| 7H | 67 | 4521 | 4371 | 6036 | 7702 | 140154 | 141687 | 195658 | 249630 | 3.3 | -33.5 | -70.4 | -1.1 | -39.6 | -78.1 |
| 8H | 1004 | 4448 | 4430 | 6117 | 7805 | 137894 | 160065 | 221037 | 282009 | 0.4 | -37.5 | -75.5 | -16.1 | -60.3 | -104.5 |
| 9H | 75 | 4589 | 4464 | 6164 | 7865 | 142272 | 139688 | 192898 | 246109 | 2.7 | -34.3 | -71.4 | 1.8 | -35.6 | -73.0 |
| 10H | 69 | 4751 | 4626 | 6388 | 8150 | 147269 | 255478 | 352796 | 450113 | 2.6 | -34.5 | -71.5 | -73.5 | -139.6 | -205.6 |

As shown in table 6.1, there is a noticeable difference in the 1997 AADT values for the existing ADOT ESAL table and the new ESAL table. This can be attributed to the fact that the existing and new ESAL tables use two different sources of AADT data. The existing ESAL table's 1997 AADT values are forecasted based on 1991 (or earlier) AADT values and growth rates. The AADT values for the new ESAL table are from an electronic version of the *Traffic on the Arizona State Highway System 1997* provided by the Arizona Department of Transportation. This difference is substantial and is amplified further when projecting values for the 2017 comparison. As expected, values are much more similar at high AADT values than at low AADT values. As mentioned previously, the forecasted AADTs are not limited by capacity and there is no maximum growth rate. Segment 874, for example, has a growth rate of 117.6 percent with a very low AADT. High variability in year-to-year growth rate for segments with very low AADT is expected.

As shown in tables 6.2 and 6.3, the cumulative ESALs comparison results mirror that of the AADT comparison. It is important to note that the values are quite similar at higher ESALs for the average ESAL table and that adding plus one and plus two standard deviations adds to the final ESAL values an additional 38 percent and 76 percent, respectively. For the low volume roads, even when the table is off by 300 percent, that only works out to be 600 ESALs (or 30 ESALs/year), which is not a significant difference.

Based upon this investigation, it is the opinion of the NCE team that the approach outlined for the new ESAL table is a valid one and does not go against the experience and engineering judgement used in the development of the current ESAL table. This comparison; however, brings out the importance of more frequent update of the ESAL table in the future to incorporate new gathered data as it becomes available.

## DEVELOPMENT OF ONE VALUE FOR ALL VEHICLES

At the request of the TAC, the project team was asked to provide a single ESAL value for all trucks. Some city or county agencies (that only have the capability to collect volume counts) come to ADOT asking for a single ESAL factor. To calculate this value, the average ESALs per vehicle class 4-13 was determined based on all WIM data collected in Arizona. Then, the average vehicle percentages per class was determined. These two values were multiplied together and then summed as shown in table 6.4.

The resulting value of 1.08 is the average ESALs per commercial vehicle. As discussed in chapter 4, in the existing ESAL table a value of 1.4 was used, which included some safety factors for increases in tire pressure and vehicle weights. It is up to ADOT to determine what value they would give to any agency, but the project team recommends using a value of 1.2, which will provide a 10 percent safety factor.

Table 6.4. Determination of a single ESAL value.

| Vehicle Class | Average ESAL per Class | Average % Class | ESALS x Average % Class |
|---|---|---|---|
| 4 | 0.87 | 4.8 | 0.04 |
| 5 | 0.21 | 21.8 | 0.04 |
| 6 | 0.82 | 10.4 | 0.09 |
| 7 | 1.64 | 2.4 | 0.04 |
| 8 | 0.61 | 16.1 | 0.10 |
| 9 | 1.71 | 36.1 | 0.62 |
| 10 | 1.31 | 2.0 | 0.03 |
| 11 | 1.86 | 5.1 | 0.09 |
| 12 | 0.97 | 0.6 | 0.01 |
| 13 | 3.73 | 0.5 | 0.02 |
| | | 100 | 1.08 |

# CHAPTER 7: ASSESSMENT OF WIM AND AVC DATA NEEDS

## EXISTING SYSTEMS

The current WIM and AVC systems installed in Arizona have been described in chapter 3 and chapter 5 (see figures 3.1 and 3.2).

## EQUIPMENT COST

The following estimated costs for the purchase, installation and maintenance of AVC and WIM equipment are for <u>one travel lane</u>. Installation costs are based upon a contracted bid for a turn-key operation. These estimated costs do not take into consideration associated factors such as roadway maintenance, repair, and traffic delays.

There are many variables that may effect the cost of installing, maintaining and calibrating AVC and/or WIM system. Probably the biggest variable will be the cost of obtaining power and telephone service to the site. The estimated costs for these services are based upon power and telephone service being within 20 feet of the site with an estimated total cost of $14,000. Other variables that affect costs are; site selection, site location, drainage, soil conditions, pavement conditions, in-roadway equipment configuration, full freeway limits, contractor installation costs, traffic control requirements, power and telephone line locations availability, equipment calibration, available manpower usage and construction equipment usage. The actual costs will very for each specific application, so these estimated costs should be used for relative comparisons only.

These estimated costs are based upon information provided by California DOT, Colorado DOT, Nevada DOT and from a presentation of WIM Technology – Economics and Performance presented at NATMEC 1998 by Andrew J. Pratt (see the estimated cost worksheets presented later in this section).

Estimated single lane installation and maintenance cost for AVC and WIM:

Permanent Automatic Vehicle Classifiers (AVC) type 2 Piezoelectric installation cost per lane is $18,280, in addition:

- Telephone and power costs are estimated at $14,000.
- Per year maintenance cost for permanent AVC per lane is $2,000.
- Life expectancy for in-roadway sensor is estimated at 4 years.

Permanent WIM type 1 Piezoelectric installation cost per lane is $25,750, in addition:

- Telephone and Power costs are estimated at $14,000.
- Per year maintenance cost for permanent Piezoelectric WIM per lane is $5,600.
- Life expectancy for in-roadway sensor is estimated at 4 years.

Permanent WIM, Bending Plate, constructed in a concrete pad installation cost per lane is $87,730, in addition:

- Per year maintenance cost for permanent Bending Plate WIM per lane is $5,600.
- Life expectancy for in-roadway Bending Plate WIM installation is estimated at 10 years.

**Cost Worksheets**

1) AVC Piezoelectric:

These estimated installation costs for AVC are for two inductive loops and one type 2 piezoelectric sensor in one lane of travel for both directions with roadside pull boxes and conduit connection to a roadside control cabinet with power and phone line connections and AVC classification equipment. No portable roadway or AVC classification equipment were considered for this estimate. Permanent AVC equipment can be removed from the cabinet and used at different locations where permanent in-roadway equipment exists for short period classification and a portable operation. The estimated maintenance costs do not include traffic data computations.

| | Equipment and Installation<br>By Private Contract |
|---|---|
| a. Control cabinets and mounts | $3,300 |
| b. Pull boxes | 710 |
| c. Detector loops | 2,100 |
| d. Power service | 7,000 |
| e. Telephone service | 7,000 |
| f. Mobilization | 3,400 |
| g. Traffic control | 2,900 |
| h. Conduit | 3,350 |
| i. Piezo type 2 cable | 3,400 |
| j. AVC equipment | 3,400 |

Two-lane estimated costs = $36,860. The estimate costs for one lane is $18,430.

Estimated maintenance costs per year per lane = $2,000. The life expectancy of AVC in-roadway equipment is estimated at 4 years.

2) WIM Cost Estimates:

Estimated costs are for in-roadway sensors: A. Piezoelectric, B. Bending Plate WIM. No portable WIM on-roadway or WIM portable equipment were considered for this estimate.

A. Piezoelectric WIM:

The Piezoelectric WIM was assumed to consist of two class 1 piezoelectric sensors, two inductive loops and one temperature sensor for one lane of traffic being monitored for both direction with roadside pull boxes and conduit connection to a roadside control cabinet with power and phone line connections.

| | Equipment and Installation By Private Contract |
|---|---|
| a. Control cabinets and mounts | $6,500 |
| b. Pull boxes | 1,100 |
| c. Detector loops | 2,100 |
| d. Power service | 7,000 |
| e. Telephone service | 7,000 |
| f. Mobilization | 3,400 |
| g. Traffic control | 2,900 |
| h. Conduit | 3,400 |
| i. Piezo type 1 cable | 8,100 |
| j. WIM equipment | 10,000 (Includes calibration acceptance testing). |

Estimated costs for two lanes = $51,500. The estimate for Piezoelectric for one lane is $25,750.

Estimated maintenance cost per year per lane is $5,600 (includes one calibration session). The life expectancy of WIM piezoelectric in-roadway equipment is estimated at 4 years.

B. Bending Plate:

The Bending Plate WIM sensors was assumed to be installed in a construction 100- by 12- by 1-ft concrete pad in a asphalt roadway. The in-roadway sensor was assumed to consist of one bending plate frame with two bending plates with sensors, two inductive loops, and one off scale sensor installed in one lane of traffic. Also, roadside pull boxes and conduit connection to a roadside control cabinet with power and phone line connections were assumed to be available.

One lane installation costs estimates:

| | Equipment and Installation By Private Contract |
|---|---|
| a. Control cabinets and mounts | $6,500 |
| b. Pull boxes | 1,100 |
| c. Detector loops | 2,100 |
| d. Power service | 7,000 |
| e. Telephone service | 7,000 |
| f. Mobilization | 3,400 |
| g. Traffic control | 6,000 |
| h. Conduit | 3,500 |
| i. Bending plate frame and plates | 14,100 |
| j. WIM equipment | 15,000 (Includes calibration acceptance testing). |
| k. Construction concrete pad | 21,900 |

Estimated costs per lane = $87,600. For two lanes, installation is $175,200.

Estimated yearly maintenance cost per lane is $5,600 (includes one calibration session). The life expectancy for the Bending Plate installed in a concrete pad is estimated at 10 years.

**Recommendations**

In deciding future investment in WIM/AVC operation, there are two considerations :

- Maintaining the WIM/AVC sites available.
- Adding additional WIM/AVC sites to the ones already operating.

To address the first consideration, the operational condition (i.e., calibration status) of the available WIM/AVC sites needs to be evaluated.

For the WIM systems at LTPP sites, the calibration status is routinely ascertained through the QA process implemented by the Chaparral software. The WIM systems at LTPP sites are very close together, especially on I-10 and I-19, for the purpose of yielding network-wide traffic data samples. Furthermore, it may possible to obtain national funding for rehabilitating some of these sites. As a result, it is recommended not to expend State funding towards rehabilitating any of the WIM systems at the LTPP sites.

For the WIM systems at other than LTPP sites, a simpler method can be followed for ascertaining calibration status. This can be done by testing the mean values of the steering axle load of three-S2 trucks against the range established from either static weigh data as already suggested under "WIM System Calibration" or, from WIM data, provided that it is obtained from an independently calibrated WIM system (e.g., WIM system at LTPP site).

For the AVC systems, at LTTP or other sites, there is a need to improve the "visual" calibration method currently used. For this purpose it is recommended to use video technology as the ground truth. Currently there are no video systems capable of classifying traffic based on the FHWA 13-bin classification scheme. However, this can have the simple form of a household-grade video-camera on the side of the road followed by manual counts from several independent observers. The advantage of a video system is that it is portable and can be moved between AVC locations to cover the entire State.

To address the second consideration, an evaluation of the truck traffic levels across the State needs was undertaken. Operating on the assumption that the greatest need is in areas of the highest AADTs where there is currently no AVC/WIM equipment the list compiled in table 7.1 was developed. In addition to the AADT factor, the other major factor was selecting classification sites that currently have no AVC/WIM systems located in their limits.

Some substitute locations for classification sites located above are: segment 76, for classification site 136; segment 102, for classification site 64; segment 79, for classification site 69.

In discussions with the TPG, seven ATRs were purchased and installed that had the capacity to collect classification data, but due to equipment and software problems (not to mention the constant pounding of thousands of vehicles per day) there is only one (on I-10 near Benson) that is currently capable of collecting vehicle classification information. ADOT should investigate the cost of getting these ATRs to collect classification data as was originally intended, and if there is a need to replace existing ATRs, ADOT should do so with equipment that can collect classification data.

Table 7.1. Recommended locations for AVC/WIM installations.

| Classification | Traffic Segment | Route | 1997 AADT |
|---|---|---|---|
| 136 | 1184* | I-10 | 218,881 |
| 148 | 833 | U-60 | 156,008 |
| 74 | 107* | I-10 | 108,332 |
| 143 | 1104 | SL-202 | 124,060 |
| 64 | 97* | I-10 | 37,495 |
| 69 | 1001 | I-10 | 102,850 |
| 144 | 610* | S-77 | 46,000 |
| 68 | 569 | S-87 | 49,624 |
| 39 | 628 | S-89 | 37,696 |
| 107 | 419 | SB-40 | 34,000 |

*Existing ATR within this segment.

Before acting on these recommended installations, ADOT should revisit the assignment of particular traffic segments to the various classification sites. Additional weight should be given to sites containing AVC/WIM systems. If these assignments (segmentation) are revised, perhaps there would not be as strong a need for some of the installations (for example, recommendations for four installations in I-10 are in table 6.4, when there are already five existing systems on I-10 related to the LTPP program).

# CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

Arizona DOT does a fine job collecting as much traffic information as their budget allows. As funding becomes available, the following recommendations would be worth pursuing:

- Increase the frequency with which classification counts are taken (annually would be ideal).
- Increase the duration of the classification counts.
- Have all counts be collected with automated equipment and use manual classification (in association with video cameras) as a method of calibration.
- Install new AVC/WIM equipment at key locations.
- Instrument all lanes at AVC/WIM locations to allow accurate counts of percent trucks and AADT.
- Convert the ESAL tables from Excel spreadsheets to an interactive database.

Other issues that should not wait for increased funding are:

- Revisit the traffic segments assigned to classification sites to place more segments in classification sites with AVC/WIM systems.
- Calibrate of the TPG AVC/WIM equipment.

## SUMMARY

This study resulted in the development of ESAL design tables that:

- Calculate annual ESALs for flexible and rigid pavements.
- Predict annual growth and assesses the reasonableness of the prediction.
- Are interactive so that a manual change of one parameter will cause the final ESAL calculation for that segment to be revised.
- Provide information regarding the capacity of each segment, with the ability to update these values in the future if additional lanes are constructed.
- Update ESAL values based on WIM data collected throughout Arizona.
- Provide a safety factor of +1 and +2 standard deviations for these ESAL values.

In addition, the following information is also provided:

- Insight into the types of data collected by ADOT.
- Formal documentation of how AADT values are calculated.
- Recommendations on AVC/WIM calibration.

- Recommendations on additional AVC/WIM installations.
- Determination of a single ESAL value for all trucks to provide other agencies in Arizona.
- Information from 11 State highway agencies on how they determine and utilize ESALs.
- Cost information on installation and maintenance of different types of AC and WIM systems.

The electronic files containing the three Excel spreadsheets (for three different ESAL calculation methodologies) is provided to ADOT on a compact disk.

## REFERENCES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